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Henry Giese
Iowa State College

S. Milton Henderson
Iowa State College

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Farm Fence End and Corner Design

By Henry Giese and S. Milton Henderson

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

AGRICULTURAL ENGINEERING SECTION

AMES, IOWA

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SUMMARY

Field surveys of farm fences show that many are in poor condition. The end construction is a critical factor in the suuccessful performance of a fence. The study herein described was undertaken to find the causes for failure, to appraise the relative value of common construction methods and to attempt to devise better ones. Particular attention has been given to labor saving in the hope that knowledge of improved methods would result in more satisfactory construction on the farm.

A field study disclosed the factors responsible for failure, gave some information on loadings to be expected and some suggestions for assemblies which might be built with a minimum of materials and labor and still be expected to give satisfactory service. The experimental work included observations of loads which might be imposed on the fence end or corner by wire fencing, and a study of forces necessary to destroy ends and corners fabricated in a variety of ways. A test was made to show the effect of time and temperature on the tension in wire fencing and the ability of two types of fence ends to resist such factors. Field tests were made in one soil type only and under approximately similar soil moisture conditions. In most cases, replications have not been possible.

The tension curve in woven wire fencing is beneficial in helping to maintain a taut condition but is not entirely effective because the elastic range is small. The manufacturer's recommendation to half remove the tension curve is not sufficiently specific, is not equally applicable to summer and winter stretching and is likely to give variable results because of differences in shape and size of the tension curve. The height of the tension curve, as well as the quality of the wire involved, definitely affects the tension necessary to remove half of the height.

Tension curves in barbwire would be beneficial in maintaining a taut fence and also in reducing the total load on the fence end. Tension springs in the barbwire may provide a simpler means of accomplishing the same result.

The load on a fence end will vary with the combinations of woven wire and barbwire used, but for 832-6-11 woven wire and three strands of barbwire, the load should be approximately 3,000 pounds. A drop in temperature may cause the load on the fence to increase as much as 50 percent. This increase is caused largely by the barbed wires.

At least two double strands of No. 9 wire should be used for tension members in a fence end.

Lengthening the span decreases the vertical force on the end post of an unanchored assembly.

A horizontal brace located at the top of the posts proved superior to other types of single span bracing.

The double span end assemblies all displayed more favorable

characteristics with respect to vertical and horizontal movement than did the single span assemblies. The single spans failed through a combination of vertical and horizontal movement, while the double spans failed as a result of the buckling of the long columns formed by the horizontal braces. The single span end post rotated about its base, while the double span end post remained more nearly vertical as it moved through the soil.

Increasing the depth of set of the double span with horizontal compression braces from 2′-6″ to 3′-6″ nearly doubled its holding power.

The 16′-6″ horizontal compression brace double span end held 214 percent of the load with 54 percent of the horizontal and 43 percent of the vertical movement of the 8′-6″ single span end.

The single span corners failed because of vertical movement of the corner post. The double span corners could not be pulled to rupture with equipment available (fig. 25), but the indications were that failure would have resulted in a considerable horizontal movement before a corner would rise out of the soil.

The operating characteristics of a single span were affected adversely when subjected to corner conditions, while those of a double span were definitely improved. This is doubtless explained by the difference in type of failure of the single and double spans. When used in a corner, one double span assembly tends to stabilize the other.

A 16′-6″ double span corner holds approximately 230 percent of the resultant rupture load held by an 8′-6″ single span corner without failing. The horizontal and vertical movements of the 16′-6″ double span corner were 12 percent and 6 percent, respectively, of that of the 8′-6″ corner at loads equal to the rupture load of the latter.

In both the single and double span corners, an increase in the span length gave an increase in the holding power, but the increase for the single span was not as great as was indicated by the tests on end structures.

Taut bracing decreased the horizontal and vertical movement of the corner post considerably, thereby increasing the holding power.

Improved performance can be secured by:

(1) Improving the resistance of end construction.
(2) Decreasing the load.

The load can be decreased by:

(1) Improving the elastic properties of the tension curves in woven wire.
(2) Constructing tension curves in barbed wires or accomplishing the same results with tension springs.

Tests on small-scale models indicated the possibility of still further increasing the holding capacity of the double span arrangement by using cross braces in both spans and applying the load to the center post.

Farm Fence End and Corner Design [1]

By Henry Giese and S. Milton Henderson[2]

Fence construction principles have received little experimental attention. Many opinions have been offered but facts concerning tested structural designs are still inexistent. An editorial published in Agricultural Engineering (3) expressed the status of farm fencing thus:

> Taking the country as a whole, it seems sure that no other part of the farm plant is so far gone into disrepair and disorganization. It seems equally obvious, in general, that few structural improvements are so quickly self-liquidating.

The farmer's present-day investment in fencing is difficult to estimate because of the variation between communities in types of farming and size of farm. Miller (7) estimates the amount of fence and investment as follows:

> The fence must be of some service to farmers, or the average farm in the United States would not have between 600 and 700 rods of fencing, nor would the average midwestern farm have 10 rods of fence per acre, for the 160-acre farm.
>
> The cost for a woven wire fence in place is about $1 per rod for a 4-foot high fence. About 80 cents of the cost of this fence is for material and 20 cents for labor.

Aitkenhead (1) makes the following statement with regard to fence costs:

> A survey of 30 farms averaging 160 acres showed a fence investment of $1,500.00 each or 10 percent of value of the farm. Costs of upkeep were 18 cents per rod per annum.

The end construction is a basic factor in the effective life of a fence. Failure of line posts usually causes only local disturbance and posts are easily replaced. Failure of the end, however, necessitates complete rebuilding of the fence. A survey was made of end and corner units on farms to determine those factors which may cause failure and also construction methods which have given satisfactory performance. Particular attention has been given throughout this study to the development of techniques by means of which a successful fence can be built with a minimum of labor. Farmers generally appear to have been unwilling to put forth the effort necessary to construct anchors which have demonstrated their ability to hold a fence in place. Vertical movement of the end post and/or

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[1]Project 618 of the Iowa Agricultural Experiment Station, in cooperation with the Farm Fencing Association.

[2]The authors wish to acknowledge the contributions of two research fellows, G. L. Hazen and M. D. Strong.

Fig. 1. Typical failure of end post and compression brace.

horizontal movement of the entire end or corner assembly may result from one or more of the following construction faults:

1. Inadequate tension member.
2. Inadequate compression brace.
3. Inadequate methods of fastening the component parts.
4. Inferior materials.
5. Inferior workmanship.

Perhaps the most evident type of failure in end and corner constructions on farms was the vertical movement of the corner or end post. In all but a few of the constructions observed there was some vertical movement. It was not possible to determine in all cases

Fig. 2. Failure resulting from insufficient depth of set.

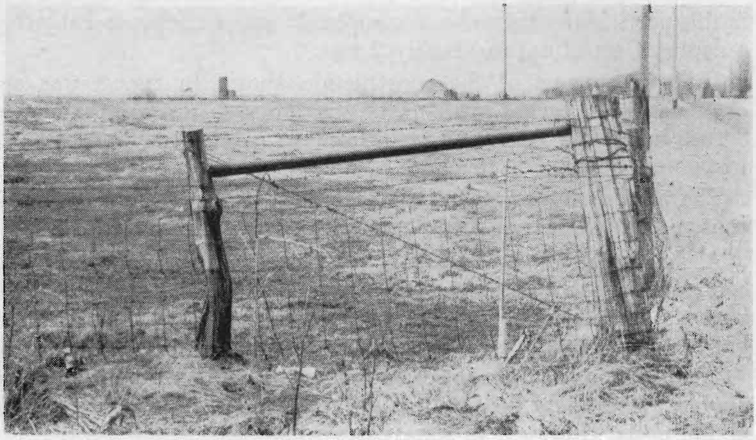


Fig. 3. A large end post may not be adequate.

whether the construction was anchored, or how deep the end or corner post was set in the ground, nor to correlate one factor with any other.

Figure 1 shows a typical failure resulting from vertical movement of the end post. The length of span was approximately 9 feet and the brace height was 3½ feet. There were five No. 12½ gauge barbwires attached to the corner post. The tension member comprised a double strand of No. 9 galvanized wire.

The length of span in fig. 2 was approximately 11 feet. There were only three barbwires fastened to the end post. The end post

Fig. 4. Failure of a short span.

in this particular structure was completely out of the ground showing a depth of set of approximately 2 feet.

The corner post of the construction shown in fig. 3 was approximately 10 inches in diameter and the span was approximately 8 feet in length. An 832-6-11[3] woven wire fence and three barbwires were attached to the corner post.

The vertical movement in this case was not as pronounced as in the constructions shown in figs. 1 and 2.

A short span of approximately 5 feet is shown in fig. 4. This construction had two diagonal braces each of a doubled strand of barbed wire. As can be seen the construction was intact structurally, but it was not holding the fence.

The horizontal movement of end posts was difficult to observe and analyze in the field because the soil tends to fill in around the base of the posts. However, in some cases where the corner construction was intact the fence was loose, indicating either that the wire had stretched or that the corner post had moved laterally. Wood compression braces less than 4 inches in the narrow dimension usually showed signs of buckling. That in fig. 2 was made of a 4"x4" wood member about 11 feet long. It showed no sign of buckling.

Failures in the tension member were rather difficult to isolate in the field because a slack tension member could be caused by other

[3]This number indicates the style of woven wire. In this case there are 8 line wires, the height is 32 inches. The stay wires are 6 inches apart, and the filler wires are 11 gauge.

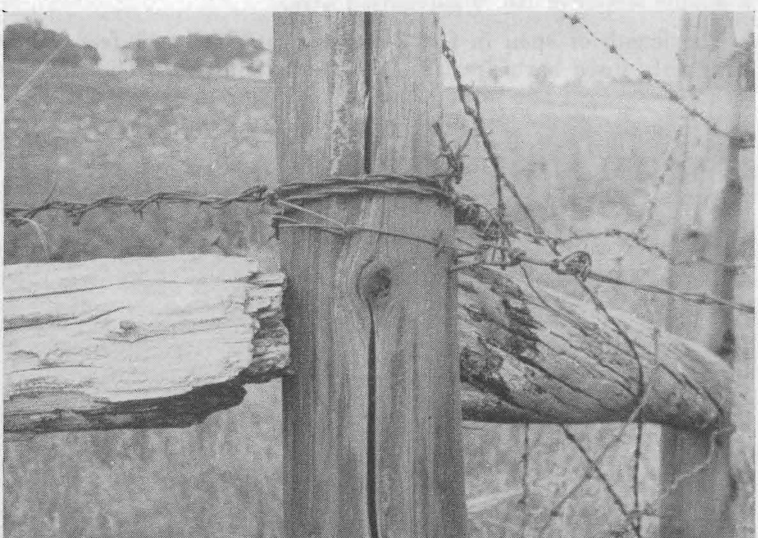


Fig. 5. Failure due to inadequate compression brace fastening.

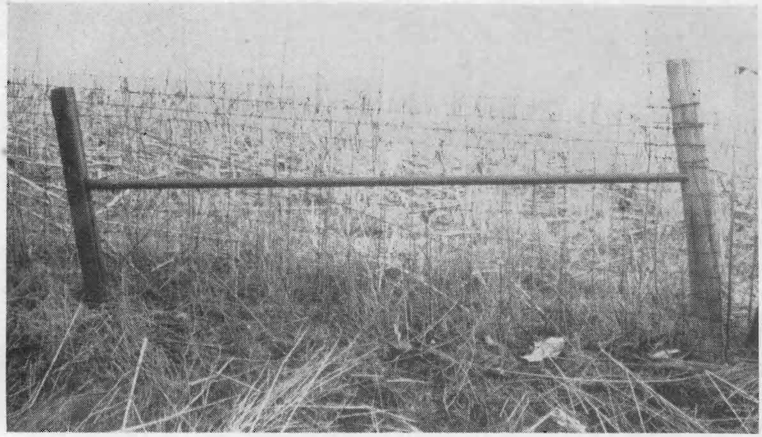


Fig. 6. Failure of tension member.

types of failures without any evidence concerning the condition of the tension member before failure occurred. In most cases the tension member was made from a double strand of No. 9 gauge smooth wire, or a double strand of barbwire. The member was tightened by inserting a rod through the strands and twisting until the entire structure had the desired rigidity. Failure of the tension member could result from stretching of the wire by overload, by untwisting of the wire, or by loosening of the wire at the points of fastening and subsequent slipping on the post. In fig. 6 the end post was set sufficiently deep in the ground to prevent rotation of the base of the post, but the load imposed by the fence bent the post above the ground line. The fence was still in fair condition notwithstanding an 11-inch lateral movement of the top of the post. The rod used to twist the tension member wire together slipped from the loop and allowed the wire to untwist.

Most compression members were toenailed to the end and brace posts. Figure 5 shows a typical connection between the end post and the compression brace. The ends of the compression member were weathered more than the remainder of the member, and the nails no longer held the brace in place. A slight load applied perpendicular to the axis of the brace was sufficient to dislodge the brace. The support furnished the brace by the wire tension members was almost as effective as were the nails. The large number of total failures caused partially or wholly by the decay of the materials used in the construction emphasized the importance of adequate structural materials.

Figure 7 illustrates two unique methods employed by farmers to carry the heavy load imposed by a fence. They are, however, not to be recommended. The stone is unsightly. The stump, in this case

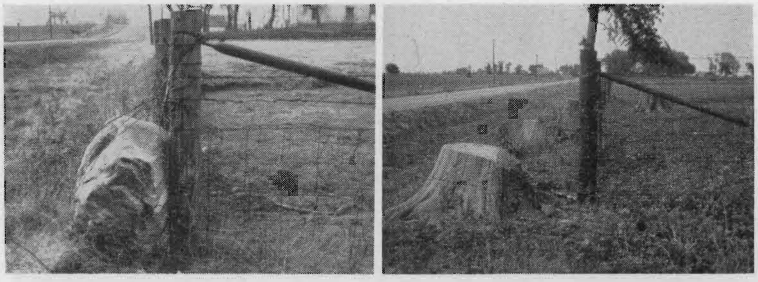


Fig. 7. Unique methods of anchoring are sometimes employed.

conveniently located is likely to decay soon, giving only short-lived performance. Adequate construction is possible without resorting to such expediencies.

The survey disclosed several successful end constructions which having demonstrated satisfactory performance, provided stimulus for some of the research herein reported. Most of these employed what might be termed a double span arrangement.

In a few cases an anchor of some type was used, but very few farmers seemed willing to spend the extra effort necessary for a construction of this kind.

The double span end shown in fig. 8 had been in service in a livestock enclosure for 4 years and was still in excellent condition. The arrangement was 1 rod long and used the first line post for the second brace post, thereby reducing the cost of the end structure. The compression braces were run from a point approximately three-

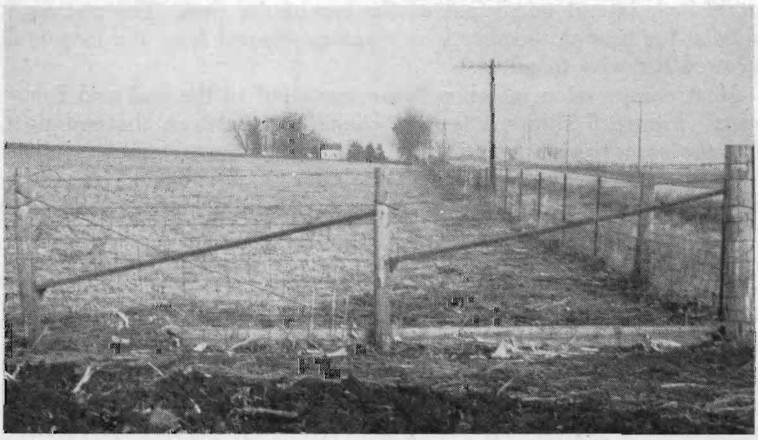


Fig. 8. This double span has given good service for 4 years.

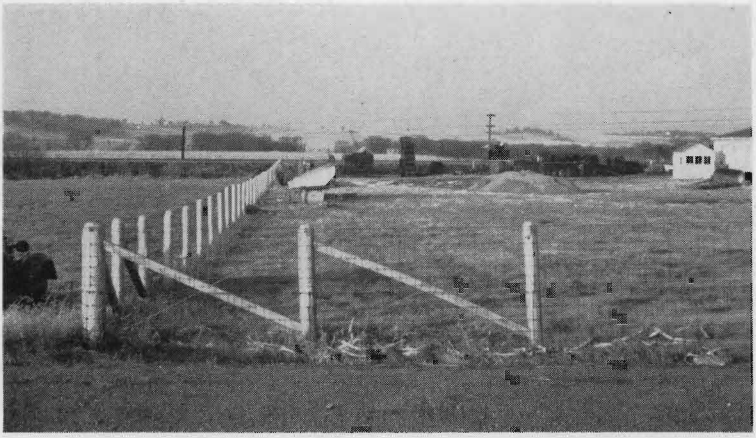


Fig. 9. This double span has held the fence well.

fourths of the above-ground height of the post to the mid-point on the brace post.

The arrangement shown in fig. 9 is in use around the highway maintenance grounds 2 miles east of Atlantic, Iowa. The fence is composed of two 726-6-9 strands of woven wire and one piece of double strand No. 12½ gauge barbwire, making a total height of 54 inches. The load resulting from this type of fencing is as severe as will be found in almost any farm fence, yet the corner construction was in perfect condition with the exception of the second compression brace which was bending slightly. There was no evidence around the post of any movement, either horizontal or vertical.

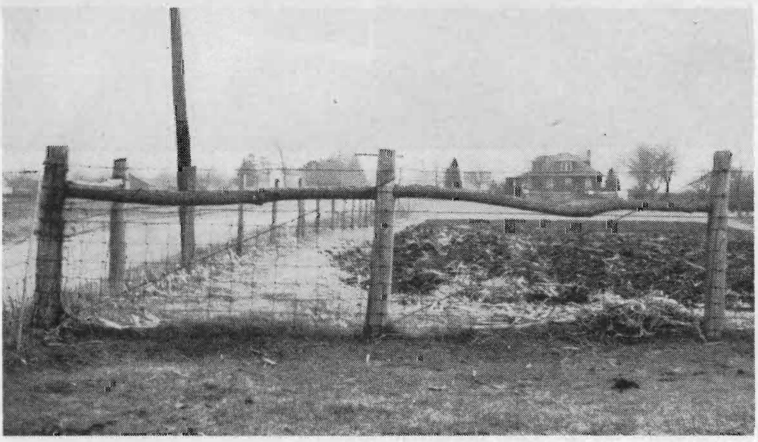


Fig 10. A double span using horizontal braces.

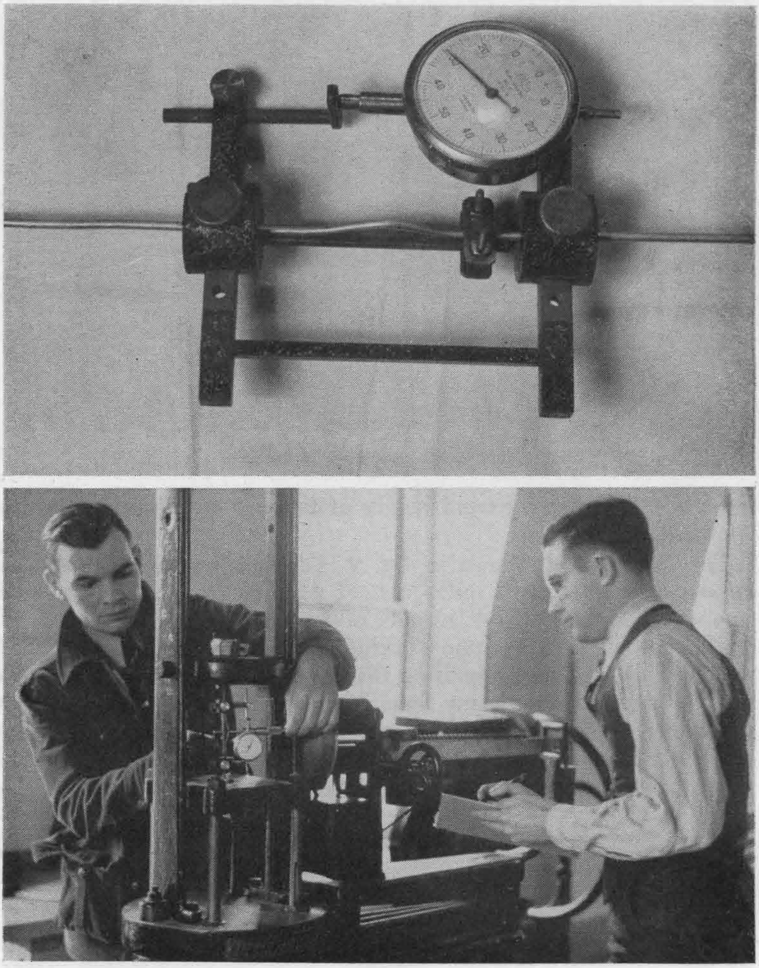


Fig. 11. Equipment used in testing tension curves used in woven wire. Top: The extensometer measure changes in length. Bottom: Loading the wire sample in testing machine.

The horizontally braced double span, shown in fig. 11, maintained a tight pasture fence after years of service. The one double strand of wire had stretched, allowing the posts to lean.

The principal problem in fence end construction arises from the fact that the loads applied to end posts by tight fence wires are above ground whereas the resistance is supplied by the soil below the ground level. This eccentric loading causes a tendency toward rotation of the fence end and exerts a vertical force which frequently lifts the end post out of the ground. In numerous fence constructions, this tendency of the end posts to rotate and lift has been met satisfactorily by nailing lugs to the bottom of the end post or by anchoring the tension member, which is fastened to the top of the brace post, to a "dead man" in the ground beyond the end post. This construction relieves the end post of the vertical force applied by the tension member.

DESIGN LOAD

The proper initial tension for stretching various wire arrangements at the time a fence is erected has not been definitely determined. Reynolds (9) gives the proper initial tension for summer stretching in a standard 832-6-11 woven wire fence as 1,600 pounds. This pulled the tension curve to one-half its tensionless size, which is the recommendation commonly given by manufacturers. The load for a No. 12½ gauge barbwire was given as 250 pounds. Hazen (5) placed a dynamometer in a standard 832-6-9 woven wire fence at the time of stretching, and the loads for two separate stretches were 2,300 pounds and 2,600 pounds. A dynamometer placed in a stretch of 726-6-11 style woven wire on a farm showed that it was under only 800 pounds of tension.

Several specimens of wire tension curves were tested (a) to determine the load imposed upon an end construction by the initial stretching of various types of wire, (b) to compare the elasticity of the crimped wire with the straight specimens and (c) to predict the effectiveness of the curve in relieving the stress in the fence caused by temperature changes.

Both straight and crimped specimens were chosen from gauges No. 9, 10, 11 and 12½ which represent the most common sizes used in fencing.

A conventional laboratory testing machine was utilized in loading the specimens.

An extensometer was constructed to determine the deformation in the tension curve during the loading period. This device with a specimen of wire in place ready for testing is shown in fig. 12. It consisted of an Ames dial gauge and two clamps pivoted on an arm opposite the dial gauge. The two clamps, containing a 4-inch length of the specimen, were made of pointed thumb screws which fastened on either side of the tension curve.

A piece of metal was clamped to the wire across the tension curve so that a micrometer could be used to determine the amount of curve removed for a given load.

The procedure followed throughout the tests was as follows: The wire on either side of the curve was straightened to fit in the jaws of the machine, the piece of metal used in taking the micrometer read-

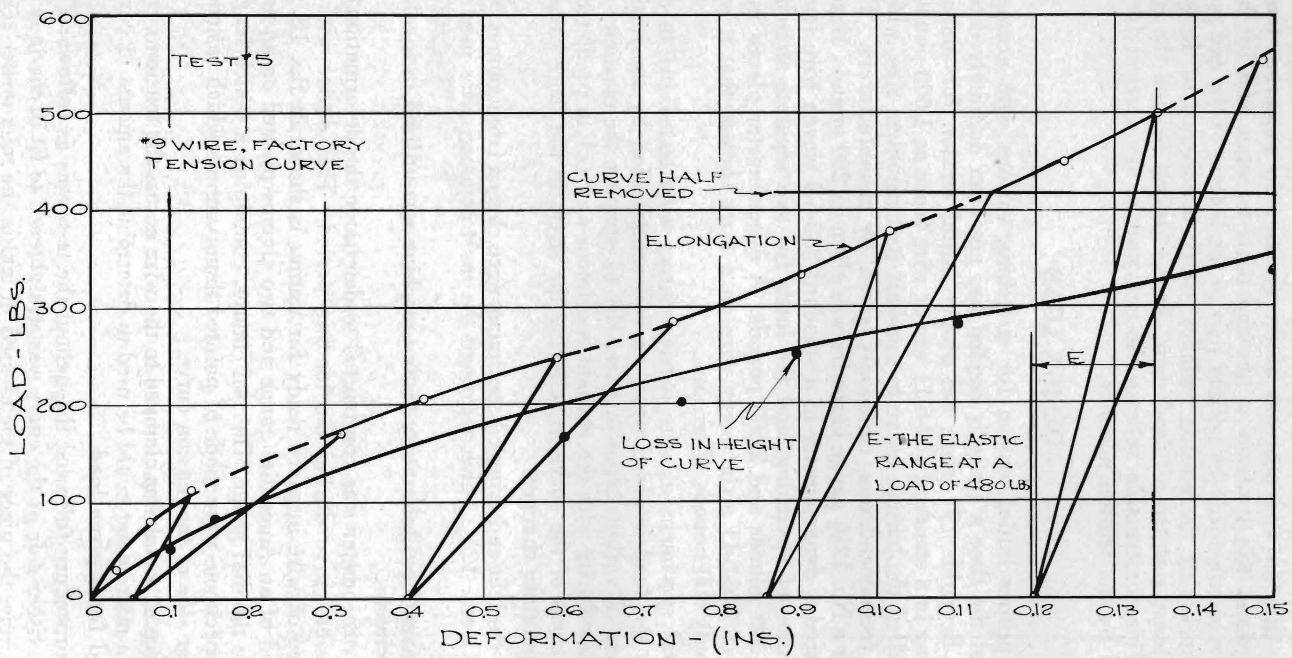


Fig. 12A. Characteristic loading curves for fence wire.

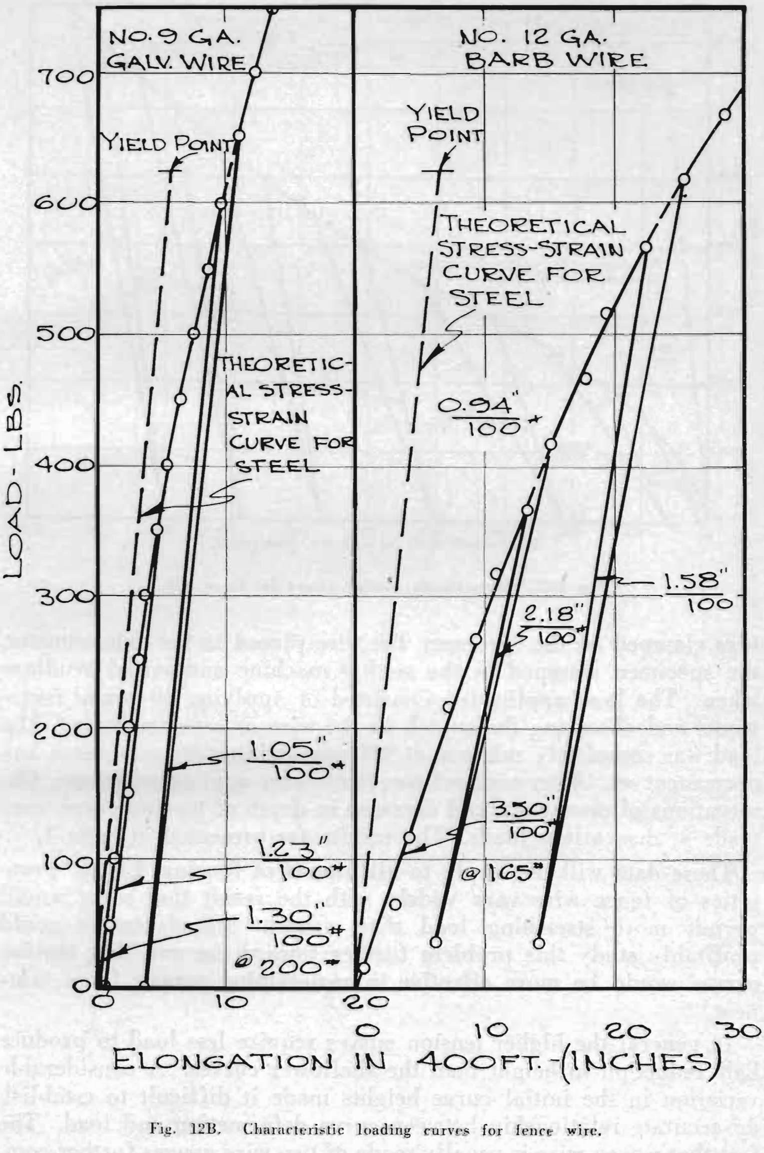


Fig. 12B. Characteristic loading curves for fence wire.

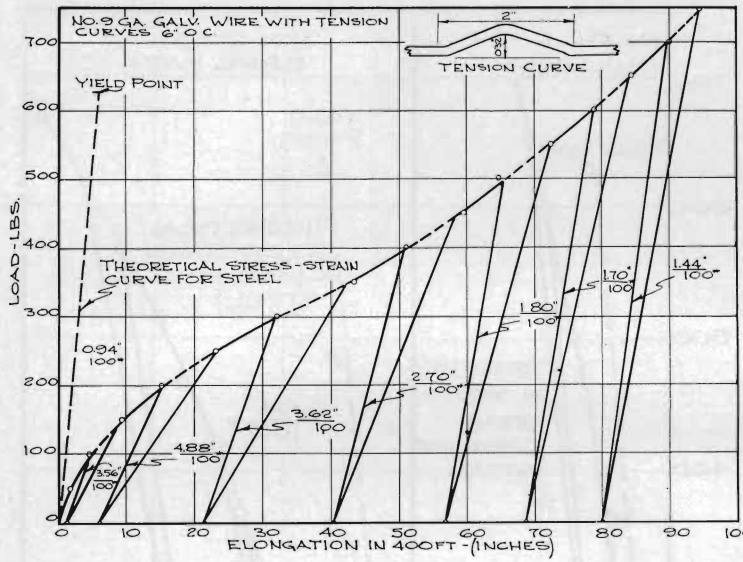


Fig. 12C. Characteristic loading curves for fence wire.

ings clamped on the specimen, the wire placed in the extensometer, the specimen clamped in the testing machine and initial readings taken. The load application consisted of applying 40-pound increments and observing the stretch in the wire at each increment. The load was completely released at 120-pound intervals to observe any permanent set. After each release, loads were applied as before. Observations of elongation and decrease in depth of tension curve were made at the various loads. The results are presented in table 1.

These data will not apply to all brands of fencing. Elastic properties of fence wire vary widely with the result that some would permit more stretching load than others. Manufacturers could profitably study this problem further toward the end that tension curves would be more effective in maintaining proper fence tautness.

In general the higher tension curves require less load to produce half reduction in height than the shallower curves. A considerable variation in the initial curve heights made it difficult to establish an accurate relationship between curve deformation and load. The fact that woven wire is usually made of two wire gauges further complicates the problem. It is, however, permissible to assume average conditions applicable to a line of fence since a great number of tension curves are represented. In a cattle fence with 1047-6-11 woven wire topped with one strand of barbwire, the top and bottom

TABLE 1. TESTS OF WOVEN WIRE TENSION CURVES.

(ALL DIMENSIONS IN INCHES; LOADS IN POUNDS.)

	Initial curve height	Conditions when curve was reduced half the initial height				Ult. strength
		Load lbs.	Elongation of curve	Elastic range	Permanent set	
			No. 9 Gauge Wire			
	.266	520	.070	.012	.058	1,440
	.324	400	.099	.011	.088	1,320
	.360	440	.124	.012	.112	1,360
	.394	324	.105	.010	.090	1,240
Av.	.336	421	.100	.011	.089	1,353
			No. 10 Gauge Wire			
	.430	600	.055	.012	.043	1,360
	.750	400	.133	.015	.118	1,320
Av.	.590	500	.094	.014	.080	1,340
			No. 11 Gauge Wire			
	.200	400	.054	.012	.042	1,040
	.210	400	.044	.010	.034	1,040
	.236	320	.041	.009	.032	920
Av.	.215	373	.046	.010	.036	1,000
			No. 12½ Gauge Wire			
	.235	140	.067	.017	.050	760
	.252	280	.067	.018	.049	880
	.255	180	.066	.019	.047	720
Av.	.247	200	.067	.018	.049	787
			No. 9 Gauge Wire (Lab. Made Curve)			
	.148	760	.081	.014	.067	1,360
	.260	520	.081	.011	.070	1,260
	.270	600	.094	.016	.078	1,500
Av.	.226	627	.085	.014	.071	1,373
			Tensile Strength of Plain Wire			
				No. 9	(2 tests)	1,440
				No. 10	(1 test)	1,400
				No. 11	(2 tests)	1,100
				No. 12½	(1 test)	800

wires of the woven fence are No. 9, each of which would require 421 pounds to reduce the height of the tension curve to one-half its value under zero stress.

The filler wires are No. 11, each requiring 373 pounds. The total necessary load for two No. 9 and nine No. 11 wires would thus be 4,199 lbs. To this add 250 lbs., the recommended tension for a barbwire, and the total initial load would be 4,449 lbs. A hog fence with 832-6-12½ woven wire and three barbwires would require an initial end load of 2,793 lbs.

The character and significance of the elastic range are demonstrated in fig. 12 which was plotted from a test chosen at random.

Further tests were made to determine and to compare the elastic properties of plain No. 9 fence wire, No. 9 fence wire with tension curves and barbwire, and also to relate or use the findings to estimate the effect of temperature upon fence tension.

No. 9 galvanized fence wire and No. 12 barbwire were used in test. The barbwire was American Glidden Cattle fence made by the American Steel and Wire Company. The two-point barbs were spaced at approximately 5 inches. The wire was twisted $1\frac{1}{2}$ turns between barbs. The cross sectional area of the No. 9 wire, 0.0173 square inches, was nearly equal to the area of the two 12-gauge wires used for the barbwire which was 0.0176 square inches. Since no single-strand wire with tension curves was available, a length of the No. 9 wire was crimped with a shop-constructed tool designed to duplicate the tension curve in the top and bottom No. 9 wires of woven wire fencing. The curves were spaced 6 inches on centers as is customary in woven wire.

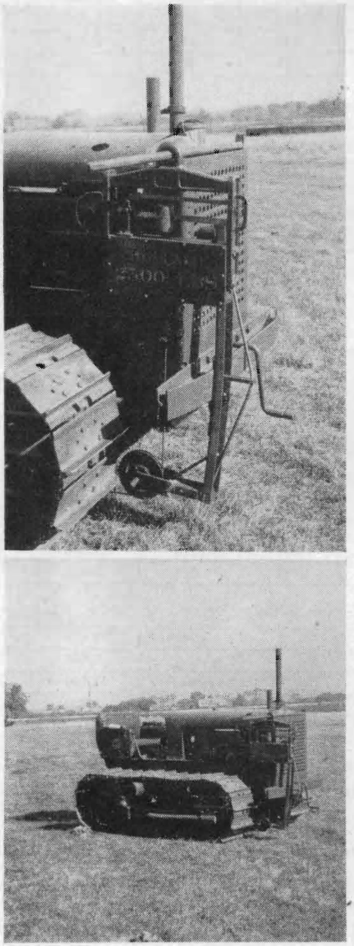


Fig. 13. Apparatus used for determining the elastic properties of fence wire. The load was applied by moving the tractor ahead by hand cranking. The pulley over which the cable passed was fitted with anti-friction bearings to minimize drag.

One end of a 400-foot length was fastened securely to a 6-inch steel pipe set in concrete, the other to a tractor which was fitted with a scale for measuring the load (fig. 13). At the 400-foot point, just behind the tractor, a board was placed under the wire to provide a reference point for measuring the elongation. A steel rule, graduated in hundredths of an inch, was used to measure the elongation, pencil marks on the board and wire being used for reference points.

The load was applied by putting the tractor in low gear and turning the crank. Observations of elongation were made for every 50-pound increment of load. For each 100-pound increment the load was removed and the amount of permanent set observed. The friction of the wire on the grass and of the pulley arrangement accounted for about 15 pounds for the No. 9 wire, both plain and with tension curves, and 70 pounds for the barbwire. These values were determined by detaching the wire from the steel post and noting the force necessary to slide the wire through the grass.

These tests were made in a level, close-cropped pasture.

The results are reported graphically in fig. 12-B. The theoretical stress-strain curves are based on data for structural steel and are incorporated in the chart as reference standards. The resistance of the No. 9 wire upon the ground was so small it was not considered in plotting the data. A 35-pound compensation, half the total resistance value, was applied to all the barbwire computations.

The wire used in these tests contained many bends of various shapes and sizes, this being a condition which is always found in coiled wire or any wire which has been handled. These bends have a small but definite elastic quality which affected the plotted results. It is this condition which gives the graph for the No. 9 plain wire (fig. 12-B) a curved characteristic rather than straight below the yield point. This condition is present in the other graphs but is covered up by the elasticity of the tension curves.

The unloading curves are of much importance since they indicate by their slope and position the elastic properties of the wire. The slope of the unloading curves gives the elasticity of the wire. The elongation at zero load for an unloading curve is the permanent set or stretch resulting from a particular load.

The value of design as it affects the elasticity may be evaluated by comparing the elasticity of the wire to the material from which it is made; viz., the slope of the unloading curve for a 365-pound load on barbwire is 2.18 inches per 100 pounds. The slope of the curve of the material, 0.94 inches per 100 pounds, from which the wire was made is 2.32 times that of the wire. Stating this relationship in another manner, the wire is 2.32 times as elastic as the material from which it is made. This value may be used as an index of elasticity. Similar values for the wires tested at various loads are tabulated below.

ELASTIC INDICES OF WIRES TESTED

	Ratio of Elasticity of Wire to Wire Material.		
Load (lbs.)	No. 9 galv. plain	No. 12 barbed	No. 9 galv. with tension curve
200	1.38	3.92*	5.19
400	1.32	2.21*	2.88
600	1.12	1.63*	1.81
800	1.11	1.38*	1.34

*Determined by interpolation.

The coefficient of thermal expansion for steel (annealed) is 6.1×10^{-6}F. The decrease in length of a 400-foot length of wire, plain, barb, or with tension curves, for a drop in temperature from 80 degrees (F.) to —20 degrees would be 0.30 feet or 3.12 inches. If the ends of the wire are fixed so no movement can take place, the decrease in temperature will cause an increase in load. For example, let us assume that when the temperature is 80°F., a 400-foot length of No. 9 wire is stretched to 380 pounds, the amount Strong found necessary to half remove the tension curve. A drop in temperature to —20°F. would increase the tension by the same amount as stretching it 3.12 inches, or to approximately 530 pounds. This would result in some permanent stretch in the wire and a consequent drop in load to 260 pounds when the temperature again reached 80°F. The barbwire under the recommended load of 250 pounds under the same temperature conditions would increase to 330 pounds, dropping to approximately 185 pounds. The No. 9 wire with the tension curves (fig. 12-C) under a 380-pound load would increase to 395 pounds, dropping to approximately 285 pounds. The significant observations to be made here are that, under the selected temperature condition which is typical, the increase in tension of a plain No. 9 wire is 150 pounds; a barbwire, 80 pounds; and a No. 9 wire with tension curves, only 15 pounds. Barbwires twisted tighter initially than the one tested would approach the plain No. 9 wire in performance, a condition which is not desired.

The results of a field study of the effect of temperature and time upon fence tension was made in connection with a time study of two end constructions and will be found reported elsewhere in this bulletin.

The loading in the fence wire may be affected by one or a combination of factors such as initial stretching of the wire, contraction of the wire caused by a change of temperature and impact or transverse loading caused by animals leaning on and running into the fence. The magnitude of the fence loads may be quite severe as is evidenced by the fact that the wire is often given a permanent set.

A good fence end construction will resist displacement when the loading caused by the fence wire is placed upon it. The demand upon the fence end, however, could be made less severe by improvement of tension curves and proper selection of metal in woven wire. The barbwire is, however, the principal offender. Not only does it possess elastic properties unfavorable to the fence end, but its location at the top of the post maximizes the moment around the point of rotation of the post.

An attempt should be made to impart similar properties to barbwire making it retain a large measure of tautness in spite of some movement of the end post or changes in wire length due to temperature variations. This might be accomplished by tension curves in the barbwire or perhaps might be obtained more easily by inserting tension springs in the barbwire line. In such a case it would be imperative to so drive the staples that the wire would be free to move within the confines of the staple. The importance of this can be visualized by considering the potential change in length of the wire in a long fence due to changes in temperature. Many 160-rod stretches of fence and those approaching 320 rods are not uncommon. Unless restrained by the ends, a fence line 160 rods in length will shrink 0.2 inch for each degree (F.) temperature drop. A 50° temperature drop from, let us say 80° to 30°, would cause a shrinkage of 10 inches or a marked increase in the load on the fence end.

STRUCTURAL ANALYSIS

The object of this analysis was to determine (a) the effect of arrangement of the structural members of an end construction on the load distribution by graphical analysis, and (b) the actual and allowable load on some of the braces found in the field.

The end construction shown in part A of fig. 14 has an arbitrary load on the end post which is transmitted by simple beam action to the panel point C and the ground line AB. The magnitudes of the portions of load transmitted to C and AB are represented by loads P_1 and P_2, respectively. The load P_2 is taken by the support which is the earth around the base of the end post. This is obviously at some variance with the actual situation as the soil is unable to provide positive support at its surface. Load P_1 is transmitted through the braces to the end and brace posts, and finally to the ground. Since load P_1 causes the vertical force on the end post, the stress diagrams for this part of the study were drawn using the load P_1 applied at point C. Space and stress diagrams for a change in length of span are given for A. Note that the longer the span the smaller the vertical component. For a given load and span no change in vertical component could be obtained by changing the arrangement of the bracing as shown in fig. 14 part B.

Lack of information regarding the support given by the soil is a limiting factor in an attempt to make a structural analysis.

From diagram D in fig. 14 it will be observed that inclining the brace post offers a possible method of reducing the vertical force. An angle of 45° seems to be the most satisfactory from the standpoint of reducing the vertical force and at the same time keeping the brace post and compression braces reasonably short.

The characteristics of the soil pressures for unbraced posts were studied in an effort to predict the possible action of the soil about the bases of the end and corner assembly posts. An analysis of

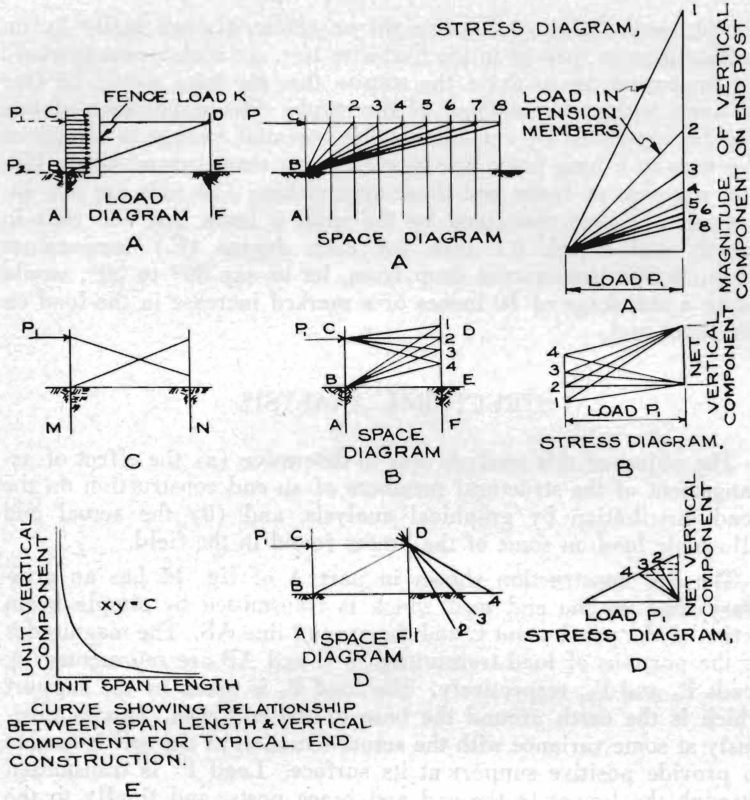


Fig. 14. Structural analysis of end constructions.

stability studies of transmission poles has been made by Seiler (8). Quoting from his paper:

> [Figure 15] represents the principal forces acting on a pole when set in compressible or granular soil and subjected to a horizontal load W acting at a distance of Z from the top of the pole. The pressures developed are commonly considered as the ordinates to a parabola whose position is such that the pressure area on one side of the pole bears the same relation to that on the other side as R does to P, these being the butt reactions.
>
> $$P = W\frac{y}{x} \text{ and } R = P + W$$
>
> In general, the ratio of R to P is not far from 1.1 and the pressure areas very closely satisfy this relation when the neutral axis of the figure occurs at a point distance $b = 0.324d$ from the butt of the pole.

Apparently the diameter of the post has little effect upon the stability. This fact is brought out by Seiler (9) in the following statement:

[Figure 15] indicates approximately the shape of the prism of earth which must be ruptured loose when a pole falls down. The point b determines the altitude of the prism, and its distance from the pole depends on the depth of setting. The shearing areas, then, are proportional to the following:

$$\text{Area A (two sides)} = cd^2 \sec \Theta$$

$$\text{Area B} = (D + kd + D)cd \frac{\sec \Theta}{2}$$

$$= (kd + 2D)cd \frac{\sec \Theta}{2}$$

$$= kcd^2 \frac{\sec \Theta}{2} + Dcd \sec \Theta$$

$$A + B = cd^2 \sec \Theta + cd^2 k \frac{\sec \Theta}{2} + cdD \sec \Theta$$

$$= d^2(c \sec \Theta + ck \frac{\sec \Theta}{2} + dcD \sec \Theta$$

Since the angle Θ is constant for any soil, the shearing area varies as the square of the depth of setting; hence the resistance of a pole to overturning in a given soil would vary approximately in the same manner, and can then be represented by the ordinates to a parabola. Hence,

$$\text{Resistance to overturning} = Md^2 + Nd$$

The diameter of the pole D is reflected in the constant N but since in practical cases D varies approximately as the depth of setting d, we can write:

$$\text{Resistance to overturning} = Md^2 + N_1 d^2$$
$$= (M + N_1)d^2$$

Of course the weight of the prism of earth to be moved affects the equation, but a careful analysis of the problem indicates that this would be reflected in the increased shearing resistance of the soil, which would tend to raise slightly the exponent of the variable d.

Obviously, even considerable variations in the diameter of the pole have little if any effect in increasing the shearing areas, and therefore resistance to overturning, because D affects only the first power term of the equation. Moreover, the soil would rupture along surfaces of weakness, more or less independent of the size of the pole butt, and this is substantiated by actual tests.

This analysis of the unbraced post provided a background for a study of the single span horizontal brace end construction. The function of the braces is to keep the end post vertical at all times. The brace post theoretically serves the one purpose of keeping braces in position, but actually it takes part of the load. This is because immediately after the structure is loaded the soil yields, the end post moves, and the brace post then takes part of the load. The brace post acts in a manner typical of the unbraced post as illustrated by fig. 16. The end post, on the other hand, acts somewhat differently. The bracing tends to keep the post approximately in a vertical position, and the entire structure has a tendency to rotate about the point on the brace post where the tension and compression braces meet. Rotation of the structure results from a combination of vertical and horizontal movement. The vertical movement is produced by the vertical component of the load carried by the tension member. From these observations it is only reasonable to deduce that the rotation of the end post in itself must be about the butt which moves not only horizontally but vertically.

The double span arrangement would act similarly to the single span with the exception that the vertical and horizontal movement for a given load would be reduced.

The work of Seiler shows that the curve of earth pressures between the ground line and rotation point is a parabola. The single

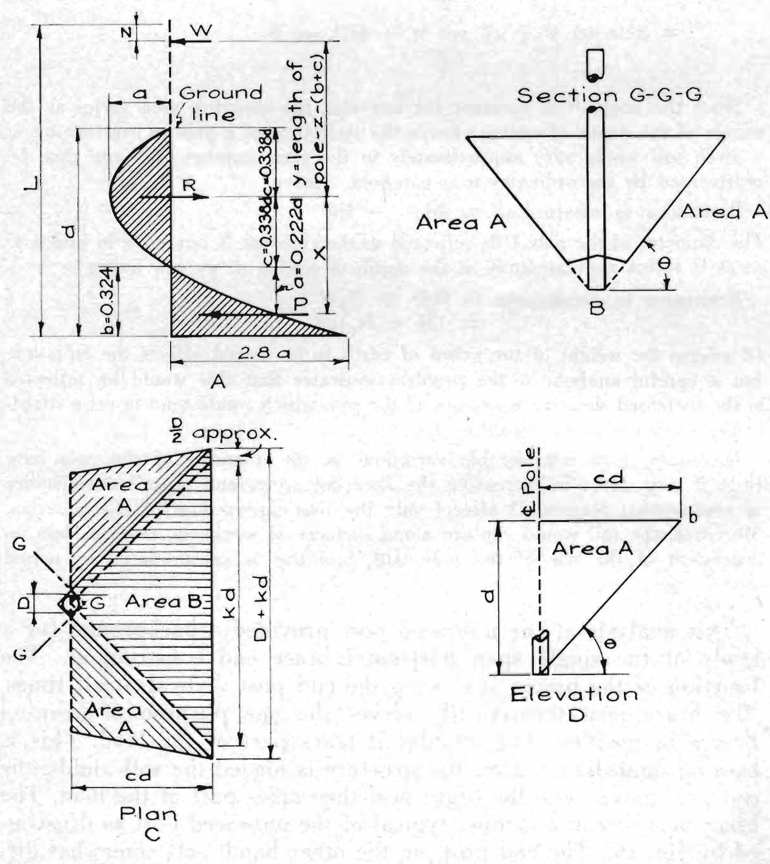


Fig. 15. Earth pressures resulting from loading an unbraced post. A shows the force distribution on a post loaded at W. Views B, C, D define approximately the mass of earth ruptured loose when a pole or post is overturned.

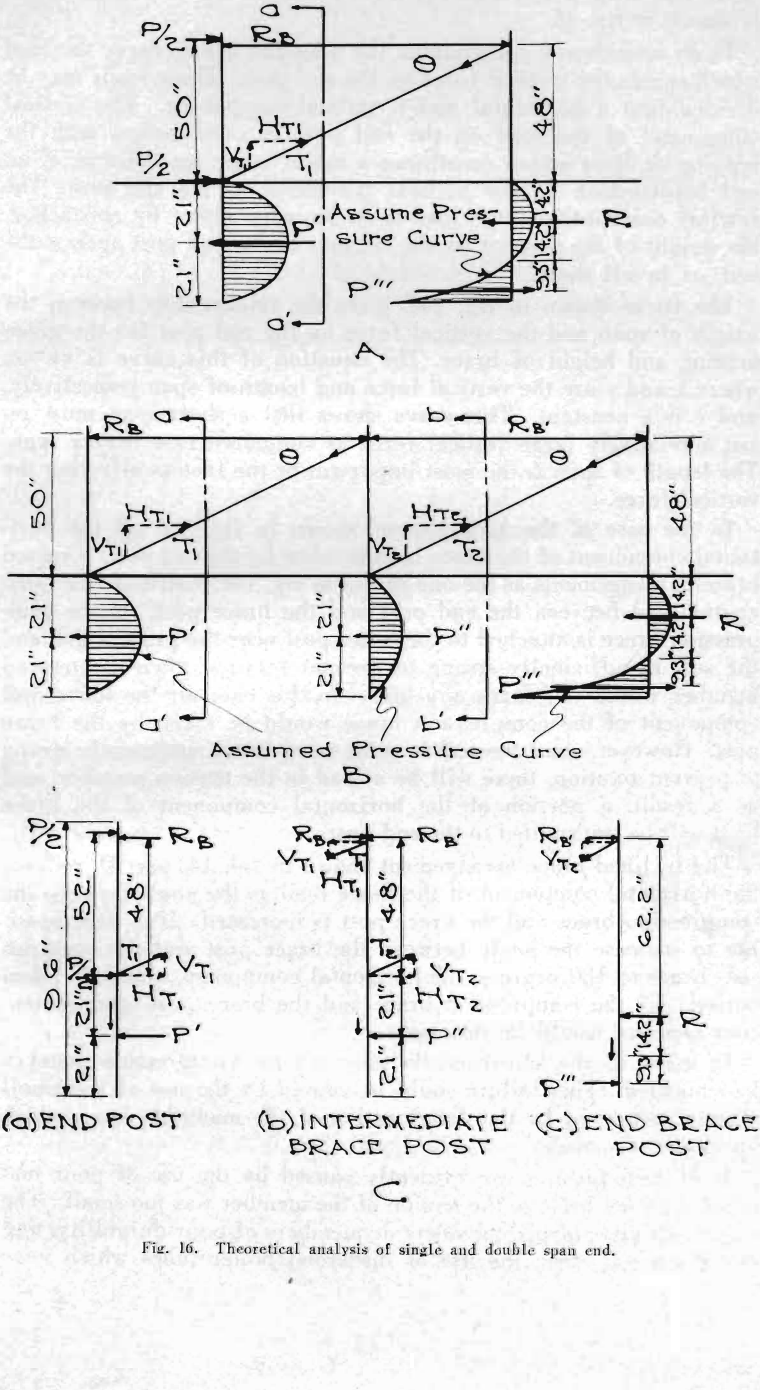


Fig. 16. Theoretical analysis of single and double span end.

span end with posts showing these coresponding earth pressures is shown in fig. 16.

In an unanchored construction the diagonal braces carry the load which causes the vertical force on the end post. These loads may be divided into a horizontal and a vertical component. The vertical component of the load on the end post in combination with the heaving of frost action constitutes a major cause for failures of an end construction by the vertical movement of the end post. The vertical component of the load must be taken either by an anchor, the weight of the post, or by the friction of the end post against the soil, or by all three.

The curve shown in fig. 14E gives the relationship between the length of span and the vertical force on the end post for the given loading and height of brace. The equation of this curve is $xy=c$, where x and y are the vertical force and length of span respectively, and c is a constant. This curve shows that a short span must resist a relatively large vertical force as compared to a longer span. The length of span is the most important of the factors affecting the vertical force.

In the case of the arrangement shown in fig. 16, all the horizontal component of the brace load is taken by the end post. Crossed braced arrangements as the one shown in fig. 14C distribute the horizontal load between the end post and the brace post. If the compression brace is attached to the brace post near the ground line and the soil is sufficiently strong to prevent rotation, then the tension member would not carry any load. In this case all the horizontal component of the compression brace would be taken by the brace post. However, since the soil in most cases is not sufficiently strong to prevent rotation, there will be a load in the tension member, and as a result, a portion of the horizontal component of the brace load will be transmitted to the end post.

The inclined brace arrangement shown in fig. 14, part D, reduces the horizontal component of the brace load as the angle between the compression brace and the brace post is increased. If it were possible to increase the angle between the brace post and the compression brace to 180 degrees, the horizontal component would be taken entirely by the compression brace and the brace post, and no tension member would be necessary.

In many of the constructions observed the compression member had buckled. This failure could be caused by the use of too small a cross section or by the deterioration of the materials from which the brace was made.

Most such failures are evidently caused by the use of poor materials and not because the section of the member was too small. The use of initially warped members or members of poor durability, and in the case of steel, the use of discarded boiler tubes which have rusted through, all lead to premature failures of the end construction.

Giese (4) recommends three double strands of No. 9 wire for a tension member for a 9-foot crossed braced arrangement. On basis of these calculations, three double strands would carry a maximum safe load of 2,700 lbs., which is ample for this type of arrangement because the tension member carries a load equal to or less than the brace load. This will depend upon the size of posts, depth of set and condition of the soil in which the end construction is set. Many of the end constructions in the field are failing because the one double strand of No. 9 wire, which is commonly used, is not sufficient.

TESTS ON MODELS

The results of the structural analysis of the fence end construction indicated that the length of span and arrangement of the structural members had an important bearing on the vertical force on the end post. Preliminary tests were made on scale models in the laboratory to determine the general characteristics of various arrangements and lengths of span on the holding power of the fence end assembly.

The dimensions of the structural members were chosen from the results of Allbaugh's (2) survey and the recommendations by Giese (4). The assemblies were chosen as a result of the field study and were representative of those found in practice.

The same end and brace posts were used throughout the tests, except that the end post had to be replaced once during the tests because of fracture.

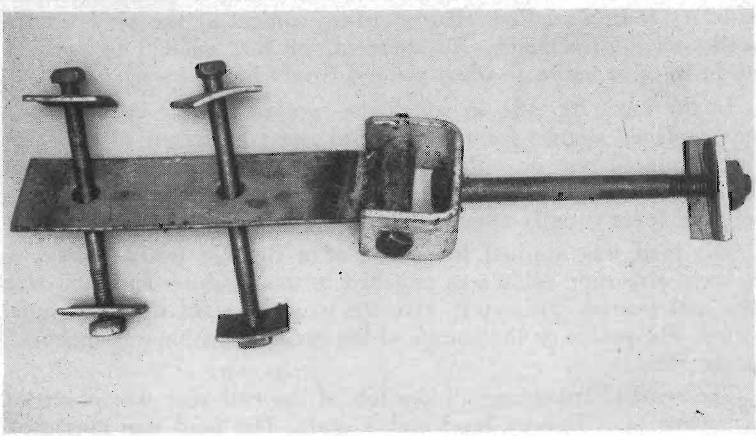


Fig. 17. Post connector.

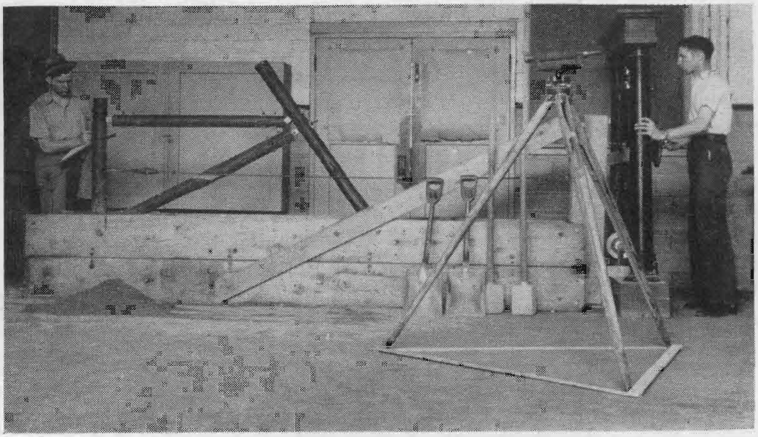


Fig. 18. Loading a model fence end.

The height of fastening the compression member to the end post was taken as 4 feet full size, or 2 feet to the scale used.

The post connector shown in fig. 17 was used in making all compression member fastenings.

Earth was eliminated because of difficulty in securing uniformity from one test to another. Dry sand confined against flowing by partitions or bearing plates was tried, but the results were indifferent. The sand would pack and slip at irregular intervals, and the end post would not pull out uniformly. Also the sand was hard to handle and pack around the base of the posts.

Sand moistened to varying degrees was found to be the most satisfactory testing medium. The moisture content of the sand finally used was approximately 3½ percent, or just enough to leave a slight trace of moisture when pressed firmly in the hand.

In the box (fig. 18) in which the specimens were set, the sand was confined against failure in lateral shear by means of two partitions placed one on either side of the end post and parallel to the specimen. These partitions served as bearing plates, transmitting the force equally over the entire cross-section of the sand.

The load was applied by means of a Buffalo testing scale. A ⅜-inch wire rope cable was attached to the machine and run over two ball bearing pulleys to give the proper height of load application. The pulley on the bottom of the testing machine was anchored to the floor.

The vertical movement of the top of the end post was observed by means of a Dumpy level and a scale. The load was measured by the testing machine, and the horizontal movement of the end post

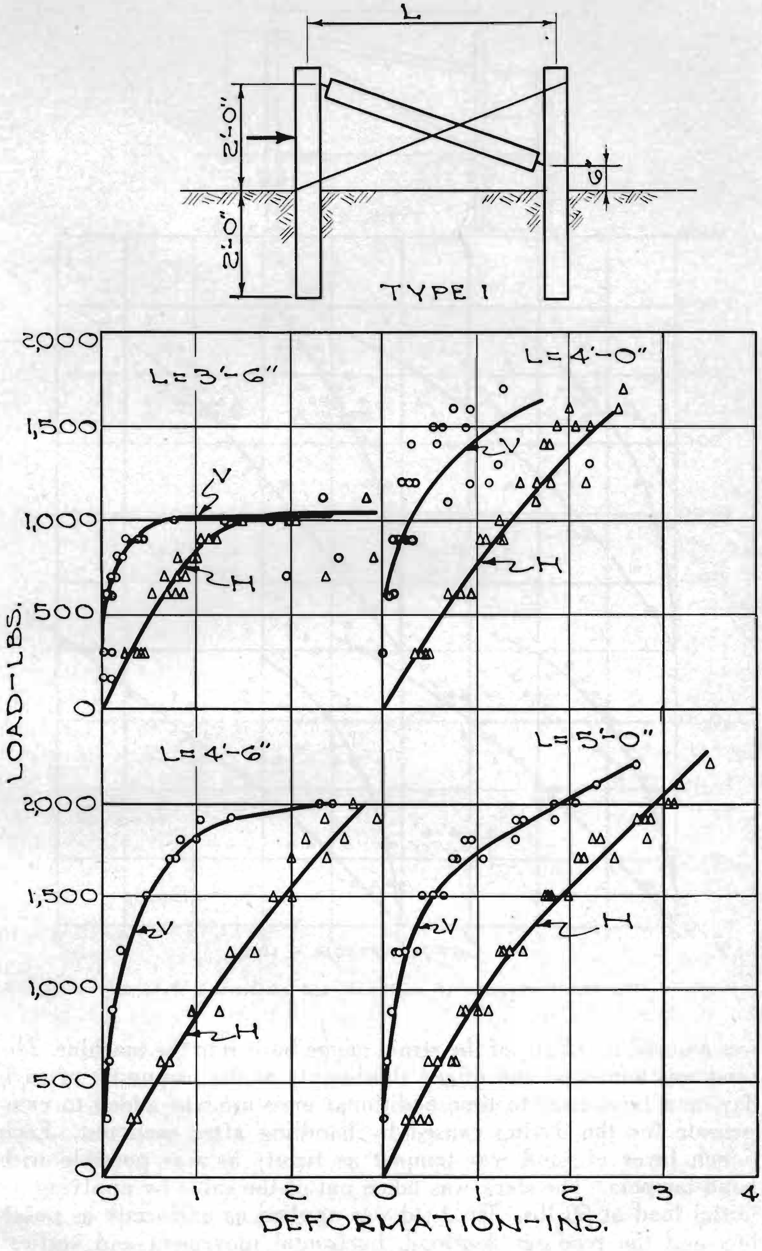


Fig. 19. Performance of small-scale end construction. Type 1.

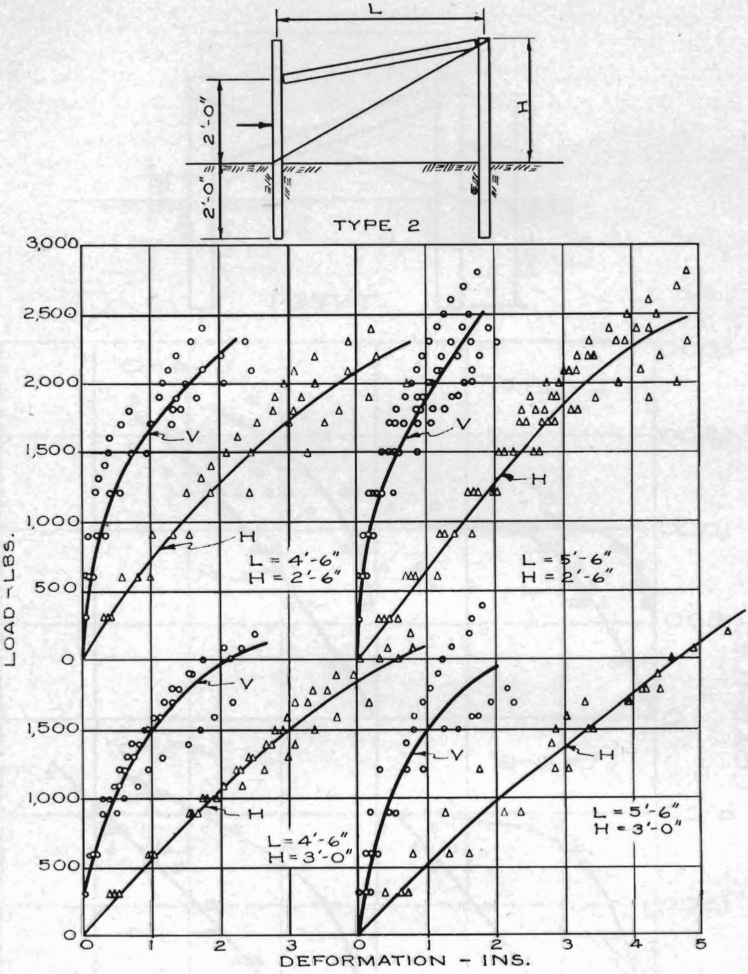


Fig. 20. Performance of small-scale end construction. Type 2.

was assured by means of the strain gauge built into the machine. The sand was tempered and mixed thoroughly at the beginning of each day, and from time to time additional moisture was added to compensate for the drying caused by handling after each test. Each 6-inch layer of sand was tamped as firmly as was possible with hand tampers. The slack was taken out of the cable by applying an initial load of 50 lbs. The load was applied as uniformly as possible, and the readings for load, horizontal movement and vertical movement were taken when the balance beam on the testing machine first raised for the desired increment of load. No attempt was made to keep the beam balanced during a set of readings.

Failure was considered as that point at which the specimen continued to move without an addition of load. This point was well defined for most of the arrangements.

The data for these tests are presented in figs. 19 to 24, inclusive. Heavy arrows indicate points of applications of loads. Each curve represents the average of several tests, H being horizontal and V the vertical movement of the end post.

These tests show rather conclusively the effect of the arrangement of the structural members on the vertical force on the end post. The conditions as they were set up in the laboratory allowed failure to occur only as a result of the vertical force on the end post. Be-

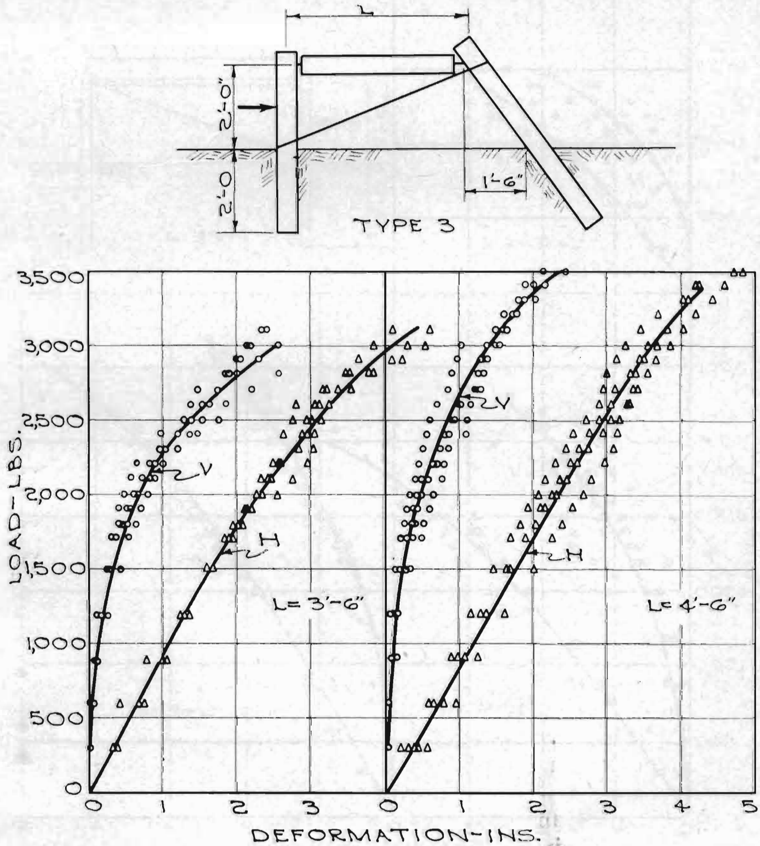


Fig. 21. Performance of small-scale end construction Type 3.

cause of the holding medium used and the confinement against failure in bearing and lateral shear, these same results would not be expected in tests under actual field conditions.

In every case, the crossed brace arrangements held the load well up to a certain point, and then would jump out of the sand.

The arrangements with braces fastened at a greater height on the brace post than on the end post all twisted considerably more than did the other arrangements as is shown by their relatively large horizontal movements.

The ends with point of load application above the junction between the brace post and the compression member (type 1) tend to rotate clockwise about the junction. This provides a lifting force

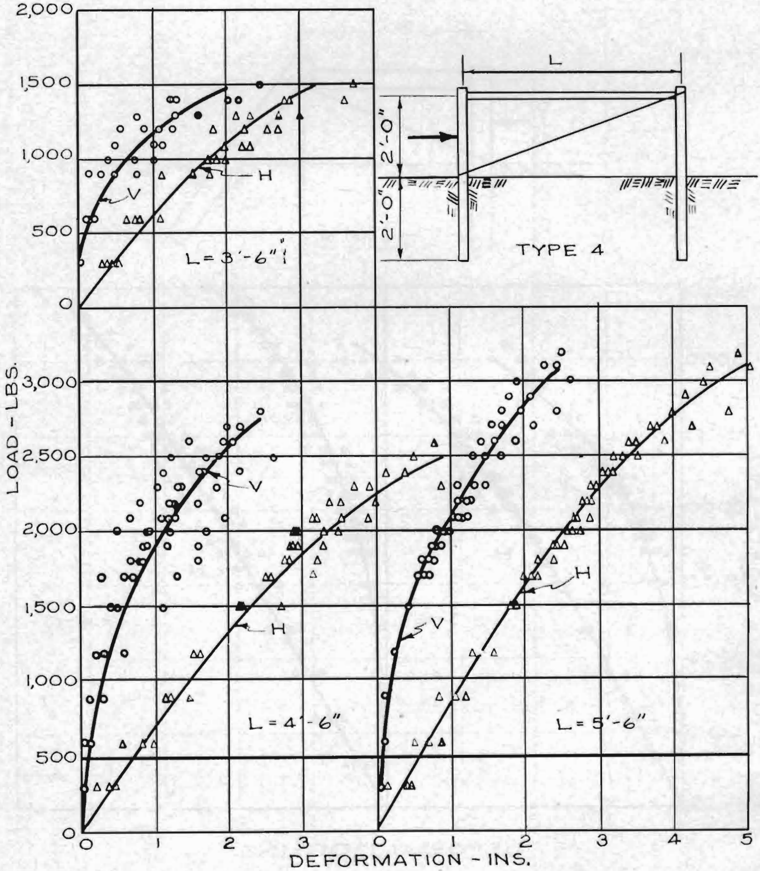


Fig. 22. Performance of small-scale end construction. Type 4.

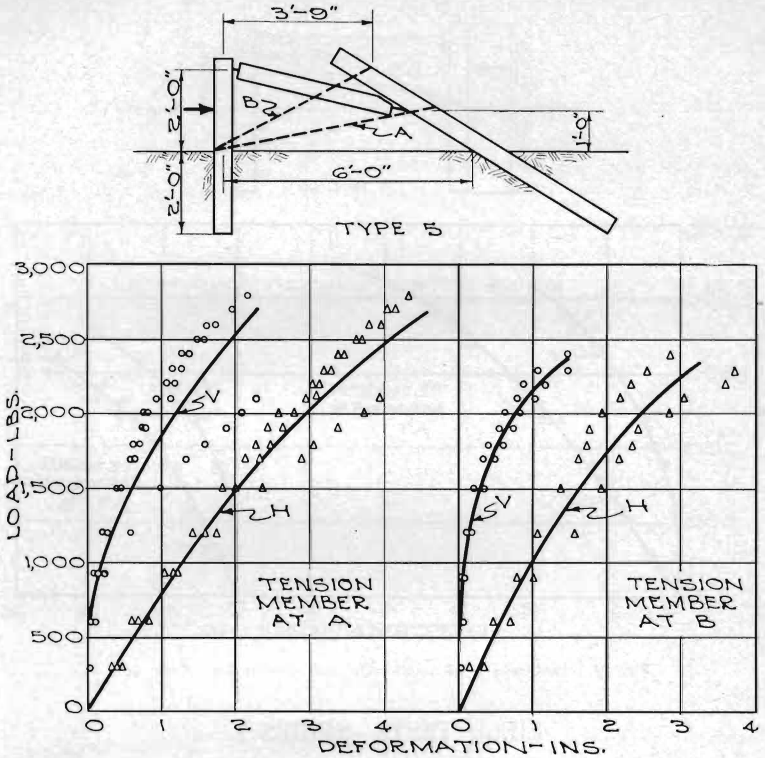


Fig. 23. Performance of small-scale end construction. Type 5.

on the end post which probably caused the posts to jump from the sand. The ends with the load applied below the junction (types 2, 3, 4 and 6) would tend to rotate in the other direction, holding the end post down.

Span length was the most important factor affecting the holding power.

The cross-braced assemblies moved less horizontally than other types, but for a given span length carried less load. Inclining the brace post of a horizontally braced assembly apparently increased its holding power.

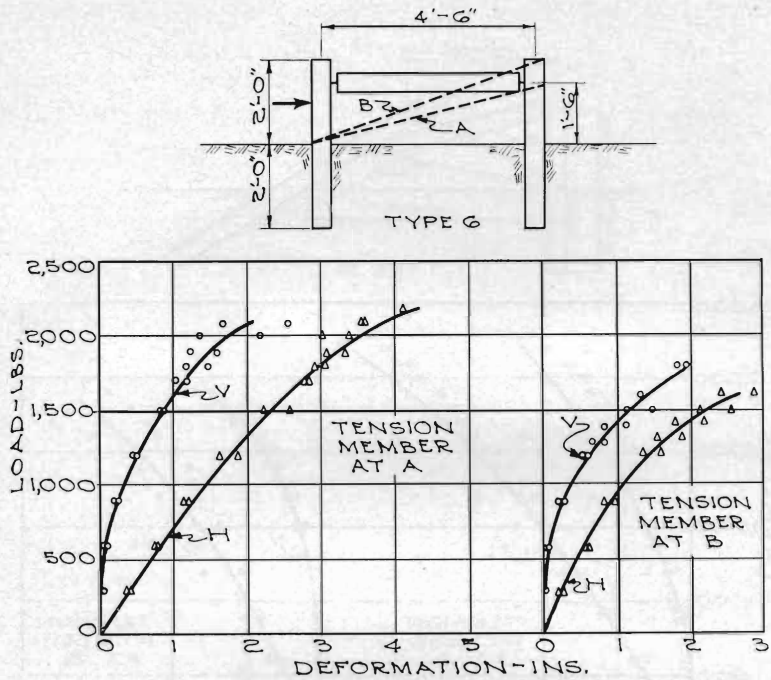


Fig. 24. Performance of small-scale end construction. Type 6.

FIELD TESTS—SERIES 1

Tests were continued in the field under conditions comparable to those experienced in actual service. Full size specimens were used and designed to secure further information on combinations which had shown up well in the sand tests using scale models. Two series of tests, spaced about a year apart, were made by different operators. The plot of ground used was selected primarily with uniformity of soil texture and moisture in mind. Tests were timed for operation under as nearly uniform conditions as possible. Soil texture and moisture content are important factors affecting the behavior of fence ends. Thus far the tests have been limited to only one soil type and to one moisture content in an attempt to get comparable tests of a large number of assemblies. Soil moisture presents a serious problem. Reference to Seiler's analysis (fig. 15) and to photographs to be discussed (fig. 27 parts A, B, C, D) later shows that the amount of soil moved by an overturning post depends to a very large degree upon the moisture in the soil. The moisture content usually varies from the surface to that at a level with the bottom of the posts. Disturbing changes can take place in the midst of a se-

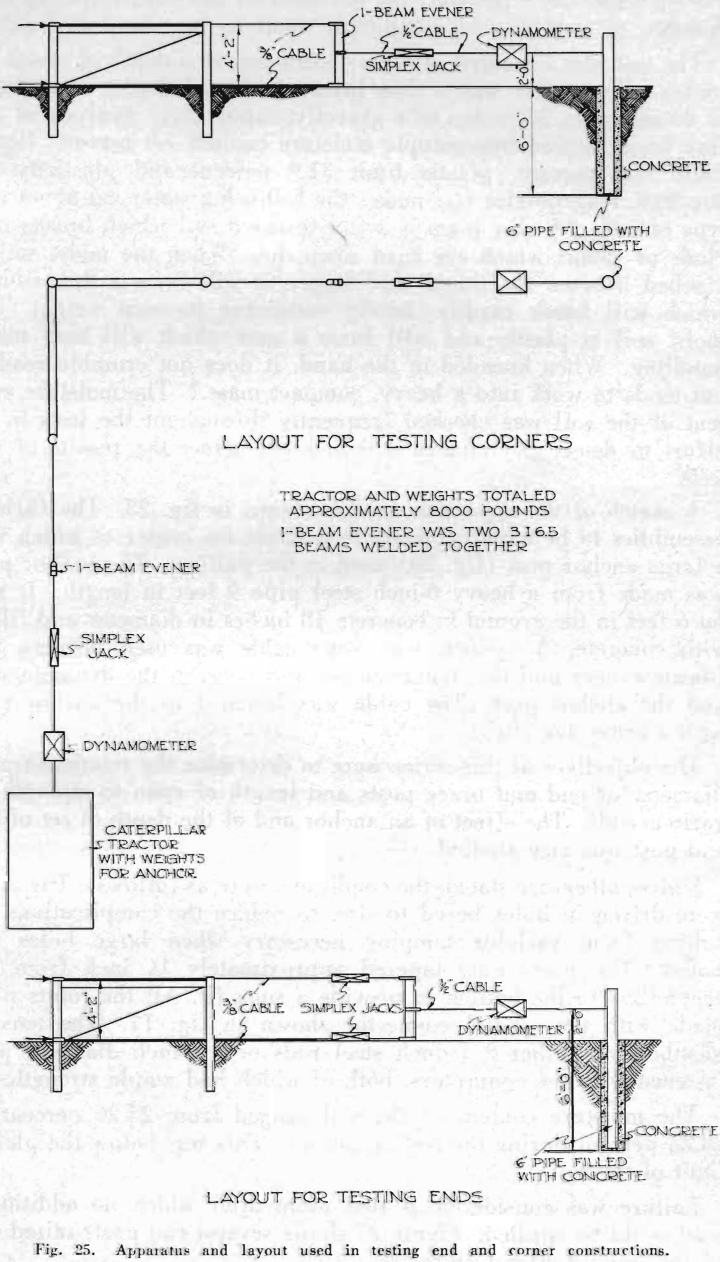


Fig. 25. Apparatus and layout used in testing end and corner constructions.

ries of tests. On a hot day, the surface soil loses moisture rapidly. A series of tests may be completely upset by an unexpected rain.

The test plot consisted of a clay loam soil to a depth of about 29 inches. Below this was a thin layer of clay changing at a depth of 34 inches to 36 inches to a gravelly, sandy clay. Analysis of the clay loam showed hygroscopic moisture content 7.8 percent, liquid limit 52.8 percent, plastic limit 31.9 percent and plasticity index 20.9. Hogentogler (6) makes the following statement about this type of soil: "A clay loam is a fine-textured soil which breaks into clods or lumps which are hard when dry. When the moist soil is pinched between the thumb and finger, it will form a thin ribbon which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast which will bear much handling. When kneaded in the hand, it does not crumble readily but tends to work into a heavy, compact mass." The moisture content of the soil was checked frequently throughout the tests in an effort to detect any change which might affect the results of the tests.

A sketch of the apparatus used is shown in fig. 25. The various assemblies to be tested were set in a circle the center of which was a large anchor post (fig. 26) used in the pulling. The anchor post was made from a heavy 6-inch steel pipe 9 feet in length. It was set 6 feet in the ground in concrete 18 inches in diameter and filled with concrete. A ½-inch wire rope cable was used between the I-beam evener and the dynamometer and between the dynamometer and the anchor post. The cable was fastened to the anchor post with a heavy log chain.

The objectives of this series were to determine the relationship of diameter of end and brace posts and length of span to strength of various ends. The effect of an anchor and of the depth of set of the end post was also studied.

Unless otherwise stated, the conditions were as follows: The posts were driven in holes bored to size, to reduce the complications resulting from variable tamping necessary when large holes are bored. The posts were tapered approximately ¼ inch from the groundline to the bottom to provide a snug fit. All the joints were made with the special connector shown in fig. 17. The tension member was either 2 $\frac{7}{16}$-inch steel rods or a 4-inch diameter post fastened with the connectors, both of which had ample strength.

The moisture content of the soil ranged from 24.26 percent to 28.23 percent during the testing period. This was below the plastic limit of the soil.

Failure was considered as that point after which no additional load could be applied. Figure 27 shows several end posts raised out of the ground after failure.

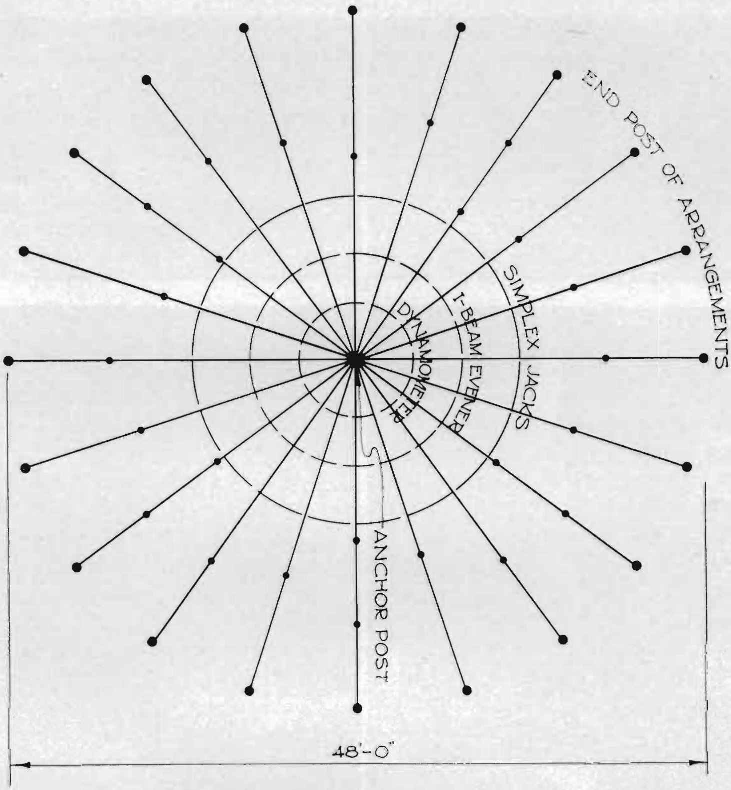


Fig. 26. Arrangement of ends around anchor post.

The specimens were loaded by means of Simplex push-pull jacks as shown in the sketch. An initial load of approximately 300 pounds was used to take up the slack in the testing apparatus and the specimen. The increment of load was taken as 100 pounds dynamometer reading, the actual load depending upon the constant of the dynamometer mechanism. The horizontal movement of the top and bottom of the end post was observed by counting the number of turns of the jack in each line. A plumb bob was used to keep the I-beam evener in a vertical position at all times. Thus if the top of the post moved further than did the bottom, a greater number of turns of the top jack would be required to keep the evener in a vertical position. The vertical movements of the top and bottom of the end post were observed by means of a Dumpy level and scale reading .2 inch. The movement of the post after failure started was not recorded. The earth was removed from around the base of the end post to determine the extent and type of failure below the surface of the ground. In most cases the soil was moved horizon-

Fig. 27. Typical soil failures showing varying angles of rupture.

tally in front of the end post over the entire depth of set, the movement being the greatest at the groundline. A half-conical section of soil in front of the end post, varying from 6 inches deep in some cases to as deep as 18 inches in others, was lifted when the post was pulled beyond the point of failure. The diameter of this section of soil at the groundline varied from 12 to 18 inches.

The mass of earth ruptured loose as cited by Seiler shows clearly in fig. 27. In A, the arc between the sides of the ruptured mass is nearly 180°. In B, C and D the arc becomes progressively less. In D, the sides of the arc are parallel (zero degrees). It appears evident that in A, the diameter of the post, within reasonable limits, would have little or no effect upon its overturning resistance. In D, on the other hand, the diameter of the post is the most important factor. In the problem of fence end design, this means that post diameter is of little importance in dry soil but becomes increasingly important as the soil takes on moisture.

In figs. 28-35 inclusive and all similar graphs, reference is made to the vertical movement V, of the end post and to the horizontal movement H_T and H_B, at top and bottom (ground level) of the post, respectively. The difference between H_T and H_B is the amount of tip or rotation which the post experienced. If H_T and H_B are parallel,

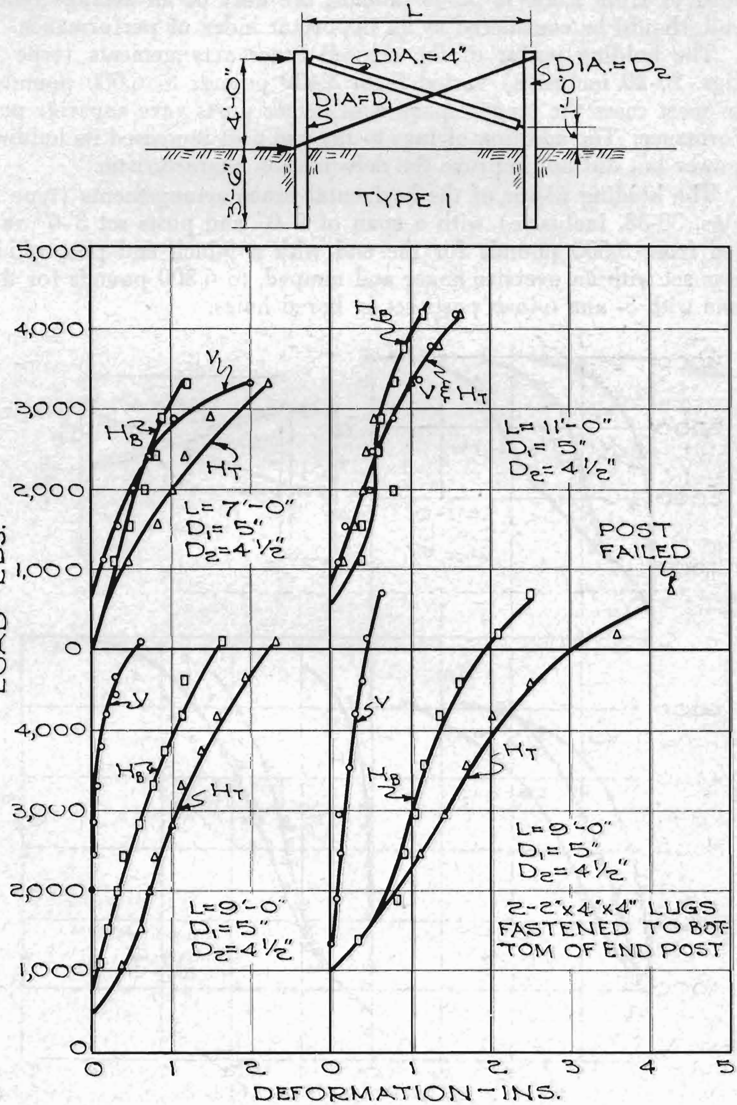


Fig. 28. Performance of crossed braced arrangement, Type 1.

the post moves laterally through the soil. If the difference between HT and HB gradually increases with an increase in load, the post is rotating. Characteristics to be desired in a fence end are little or no vertical movement, parallel movement of HT and HB (both of which should be small) and high strength at failure. The deformation at a load of from 2,500 to 3,000 pounds, the duty of an average fence end, should be considered as an important index of performance.

The holding power of the crossed brace arrangements (type 1, figs. 28-29 inclusive) varied from 3,400 pounds to 6,000 pounds; in most cases the longer spans with larger posts gave superior performance. The addition of lugs to the end post increased its holding power but did not improve the deformation characteristic.

The holding power of the horizontal brace arrangements (type 2, figs. 30-33, inclusive) with a span of 9'-0" and posts set 3'-6" varied from 3,500 pounds for the end with a 9-inch end post which was set with an oversize auger and tamped, to 6,300 pounds for the one with 5- and 6-inch posts set in bored holes.

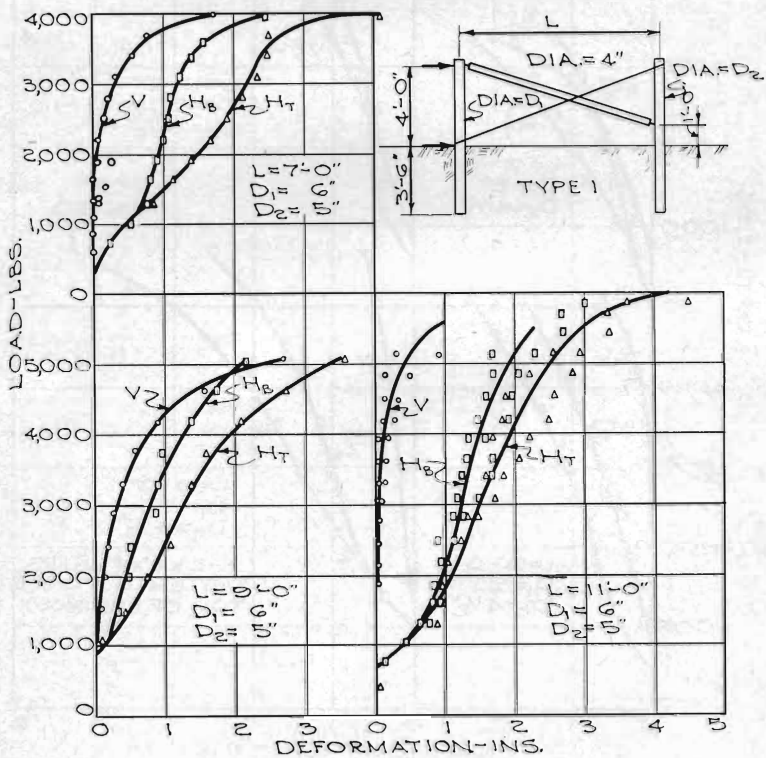


Fig. 29. Performance of crossed braced arrangement, Type 1.

Note that for comparable conditions the horizontal brace arrangements had less vertical and more horizontal movement than the crossed brace arrangements, although the holding power was superior.

The end with the wire tension member (fig. 30) had an excessive amount of horizontal movement, the wire failing at 5,000 pounds.

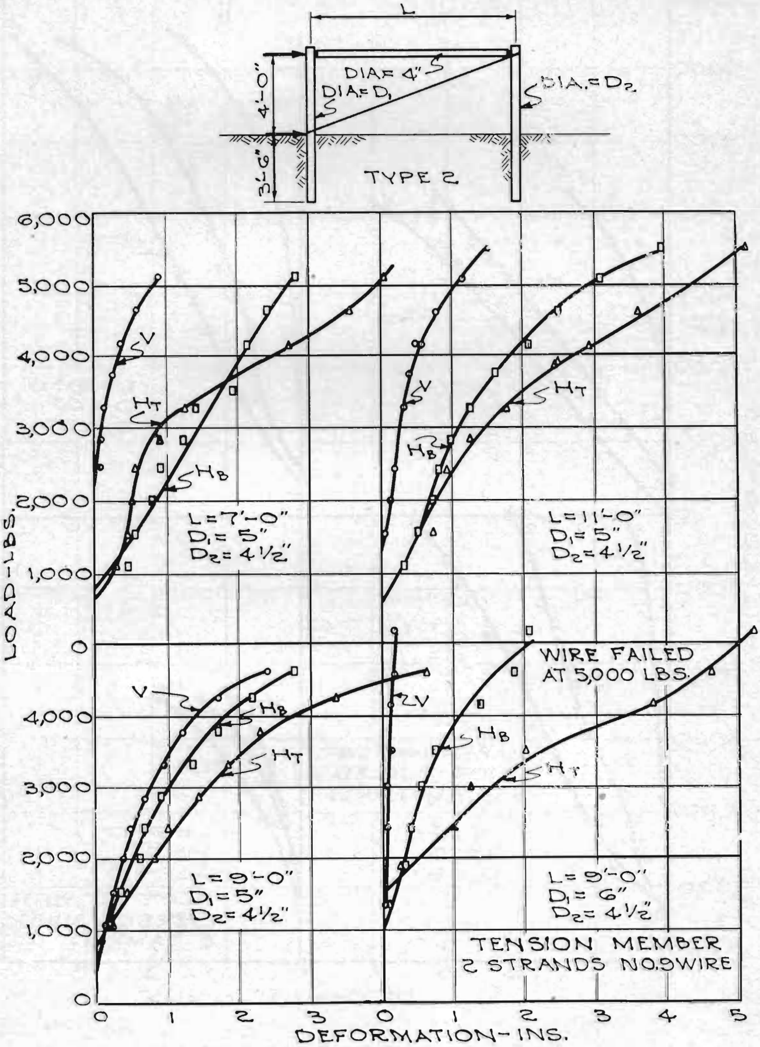


Fig. 30. Performance of horizontal braced arrangement.

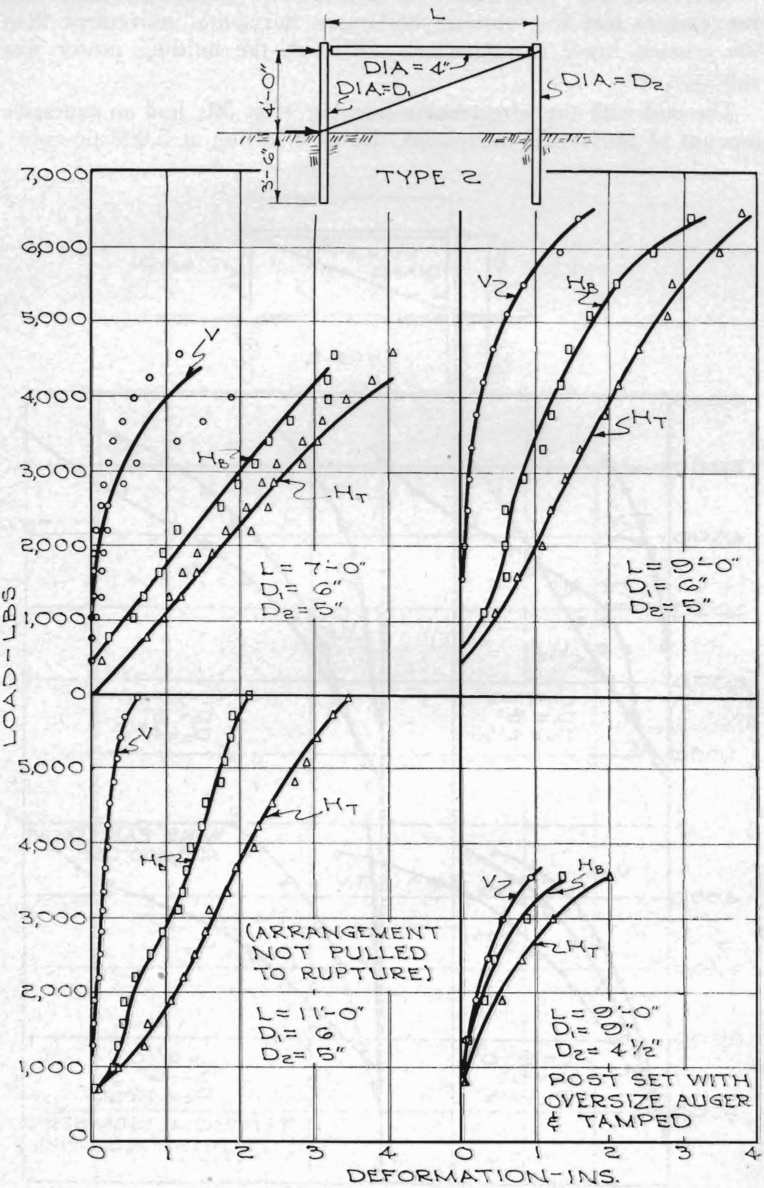


Fig. 31. Performance of horizontal braced arrangement.

A deep set end post (fig. 32) permitted a greater load but did not exhibit superior performance at lower loads.

An anchor or dead man (fig. 33) increased the strength and decreased the deformation.

Lowering the brace (fig. 33) changed the performance characteristics but did not improve them.

The inclined brace post arrangements (type 3, fig. 34) showed no general superiority.

Neither of the double span arrangements (type 2-1 and 2-2, fig. 35) could be pulled to failure. However, type 2-2 deformed much more than type 2-1, thus indicating inferior performance.

FIELD TESTS—SERIES II

The object of this series was to study the holding power of the double fence end, to determine the loads carried by the bracing members, and to study the performance of arrangements when set up as corners.

The method of end construction was simplified somewhat to provide designs which could be constructed more easily on the farm.

All the posts were set in oversize holes and tamped unless otherwise stated.

The compression members were fastened to the posts with Teco toothed ring connectors (fig. 36). Unless otherwise stated, all tension members were two double strands (4 wires total) of No. 9 wire twisted. The rod used for twisting the wire was left in the wire and hooked over the compression brace to keep the wire from untwisting. The horizontal movement was measured from a reference point established behind the end post.

The method for testing the corner constructions is shown in fig. 25. Measurements were made as for ends. The load on the tension and compression members was measured by a dynamometer and two calibrated compression springs (fig. 37). The moisture content of the soil varied from 13 to 28 percent during the series of tests.

The series of tests with single ends and corners (figs. 38-41) was made to observe the performance of the single arrangement when used on a corner, to check the effect of *method of set* upon strength, and to determine the load on the individual brace members. The superior performance of the end set in holes bored to size when tested at once is shown conclusively in fig. 38. Note that the arrangement had comparable performance characteristics when used as a corner (fig. 39). The load on the individual members is shown graphically in fig. 39. Additional member load observations were made on a longer span (fig. 40). The longer span, tested in a corner assembly (fig. 41), was found to be better than the shorter span.

Tests of double span ends and corners (figs. 42-48) were made to check the results of similar ends tested in series 1 and to secure data on the effect of depth of set. The center post twisting out of line was the major cause of failure. The end set 2½ feet deep (fig. 43) was definitely inferior to the comparable end with 3½-foot set (fig. 51). The results of three tests of a short double span corner are shown in figs. 44, 45 and 46. Some difficulty was encountered

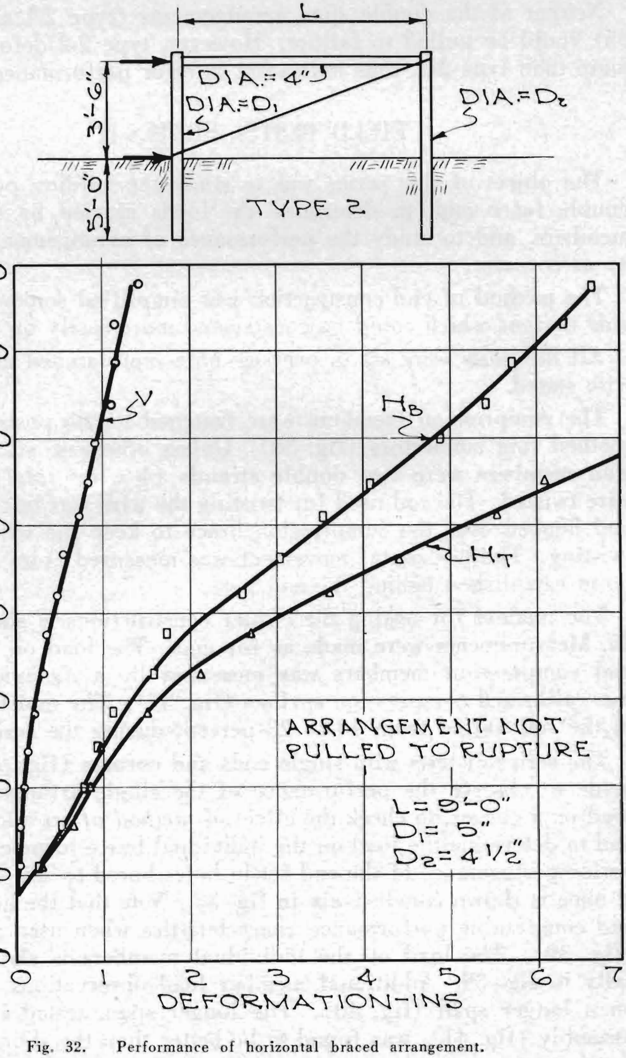


Fig. 32. Performance of horizontal braced arrangement.

due to equipment failure. The variation in these results is believed due in the main to variation in soil structure and soil moisture.

Figure 47 which has no tension member in the second span is little better than a single end. That portion of the load transmitted by the second compression member must be taken entirely by the end brace post which, having no bracing, can withstand little load. When the first tension member is absent (fig. 48), part of the load is taken by the post bearing on the soil, the other part being transmitted to the top of the second span. Consequently, the load on the second span is less than on a single similar span. The results demonstrate the importance of the tension members, especially in the second span.

The comparative performance of tension members made of two

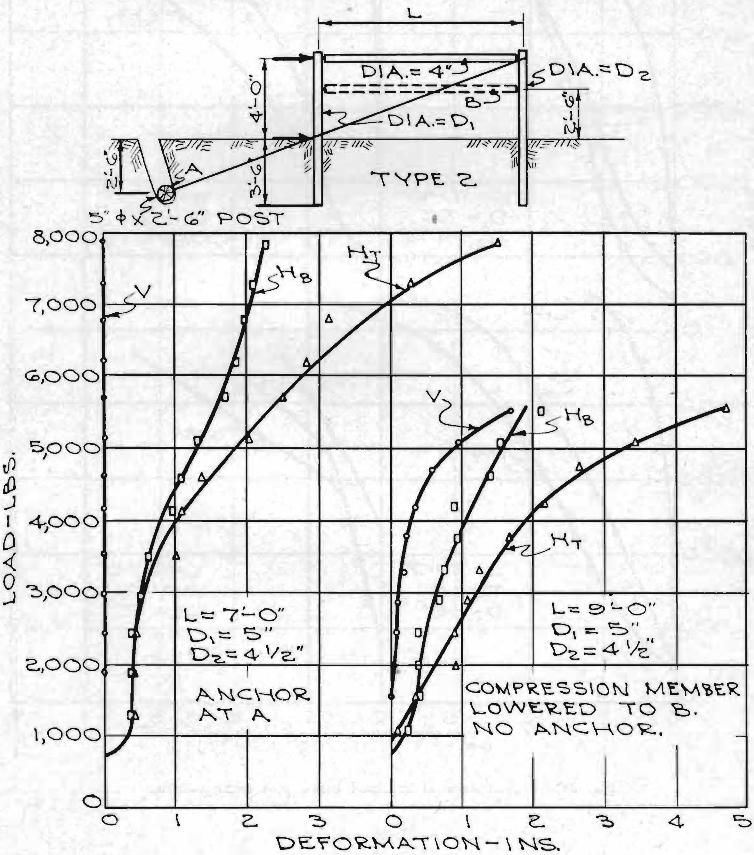


Fig. 33. Performance of horizontal braced arrangement.

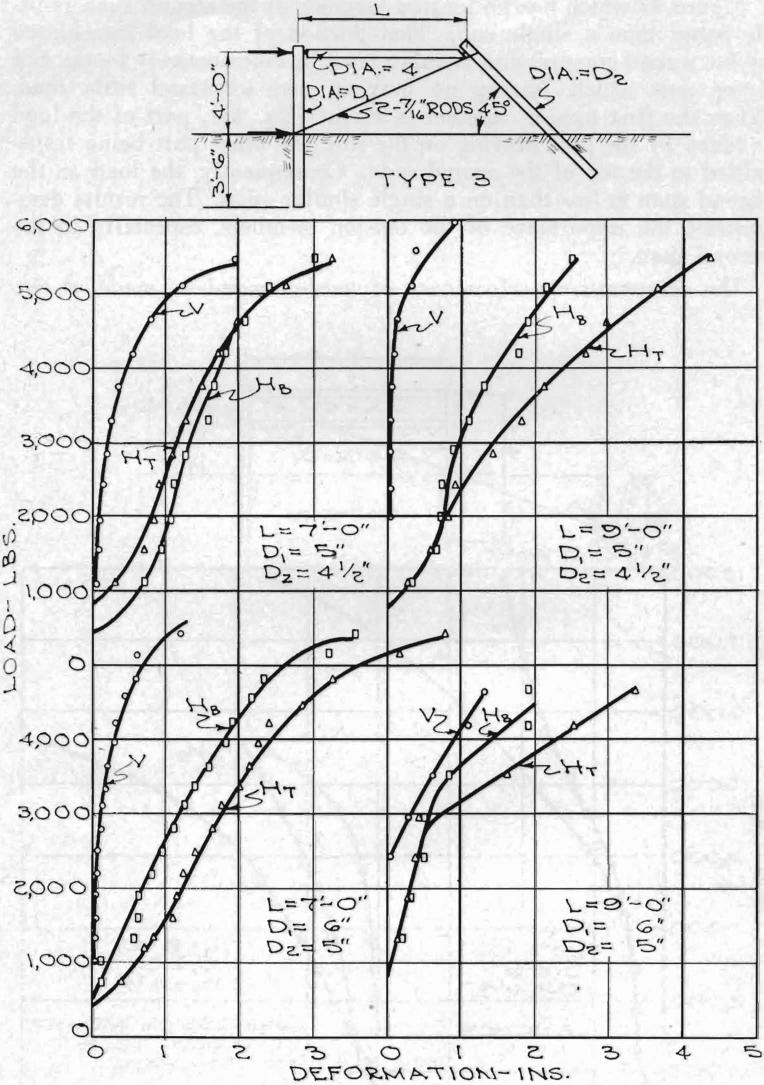


Fig. 34. Performance of inclined brace post arrangements.

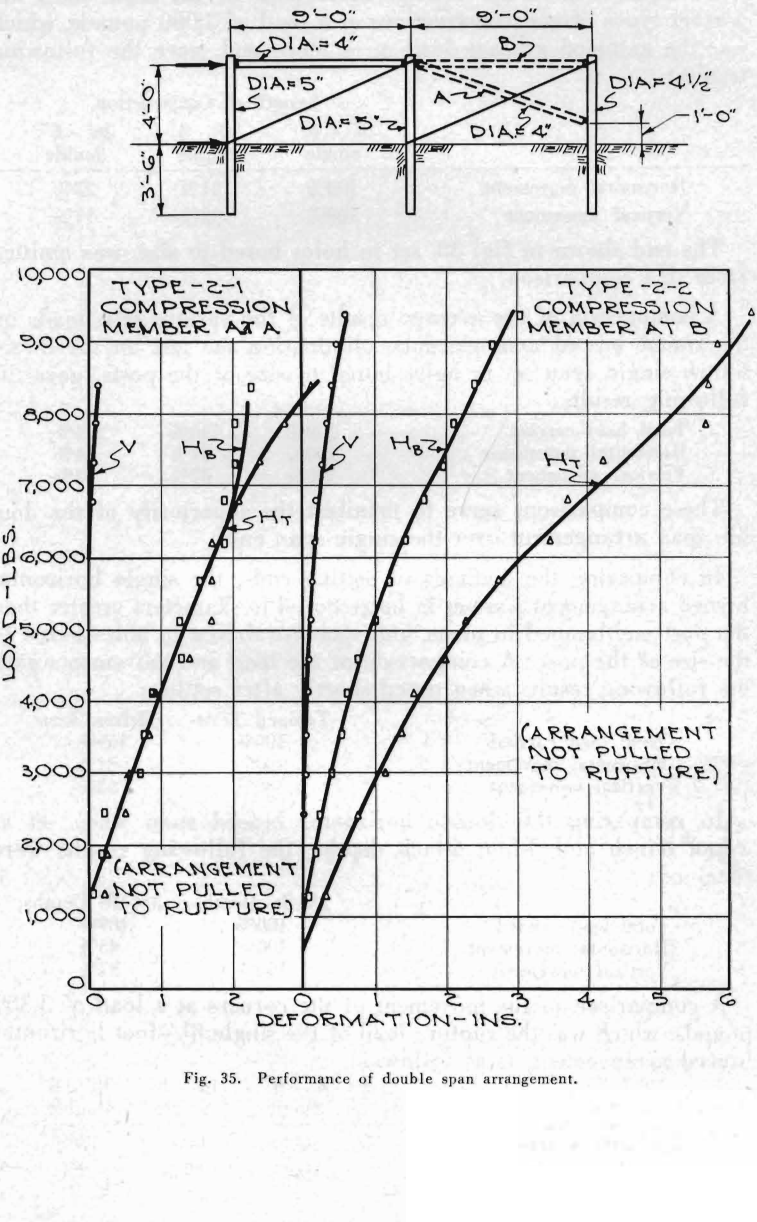


Fig. 35. Performance of double span arrangement.

and four strands of No. 9 wire are demonstrated in fig. 49. The loads on both tension and compression members are shown in figs. 49, 50 and 51.

A comparison of the average movements of the three most important types of end constructions at a load of 3,000 pounds, which was the assumed average load on a fence end, gave the following results:

	Length of Construction		
	8′ - 6″ single	10′ - 8″ single	16′ - 6″ double
Horizontal movement	100%	51%	23%
Vertical movement	100%	32%	17%

The end shown in fig. 38, set in holes bored to size, was omitted from this comparison.

A comparison of the average results of the various tests made on horizontal braced arrangements, eliminating the test on the 8-foot 6-inch single span set in holes bored to size of the posts, gave the following results:

Total load carried	100%	146%	214%
Horizontal movement	100%	81%	54%
Vertical movement	100%	37%	43%

These comparisons serve to manifest the superiority of the double span arrangement over the single span end.

In comparing the methods of setting ends, the single horizontal braced arrangement was set in holes bored to diameters greater than the post and tamped in place, and was also driven in holes bored to the size of the post. A comparison of the load and movements gave the following results when tested shortly after setting:

	Tamped Tests	Driven Tests
Total load carried	100%	169%
Horizontal movement	100%	84%
Vertical movement	100%	63%

In comparing the double horizontal braced span when set at 2-foot 6-inch and 3-foot 6-inch depths, the following results were obtained:

	2½ ft. Depths	3½ ft. Depths
Total load carried	100%	189%
Horizontal movement	100%	45%
Vertical movement	100%	57%

A comparison of the movement of the corners at a load of 3,300 pounds, which was the rupture load of the single 8½-foot horizontal braced arrangement, is as follows:

	8′ - 6″ Single	10′ - 8″ Single	13′ - 8″ Double
Horizontal movement	100%	66%	18%
Vertical movement	100%	84%	9%

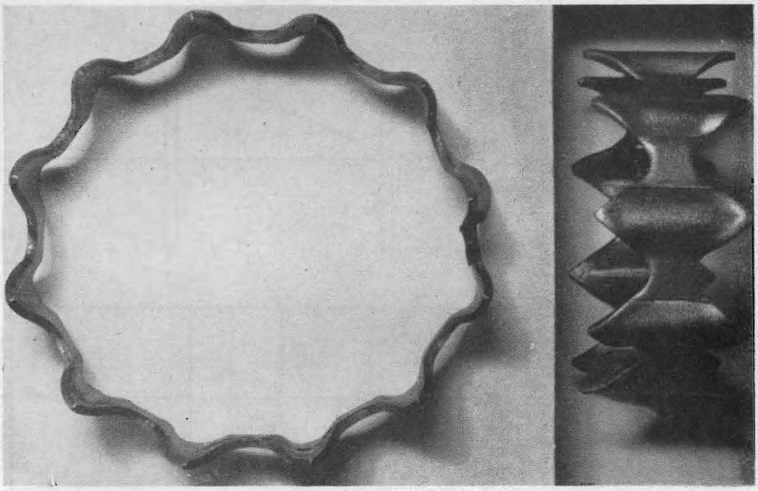


Fig. 36. Connector used for fastening wood braces.

The corner arrangement recommended from these tests is composed of two end arrangements at right angles to each other with members the same size as those recommended for the end, with the exception of the corner post which should be 6 inches in diameter. This arrangement required approximately 4½ man-hours to erect.

Experienced fence contractors report 8 man-hours required for an anchored corner construction.

When the double span arrangement was set 2½ feet deep, the

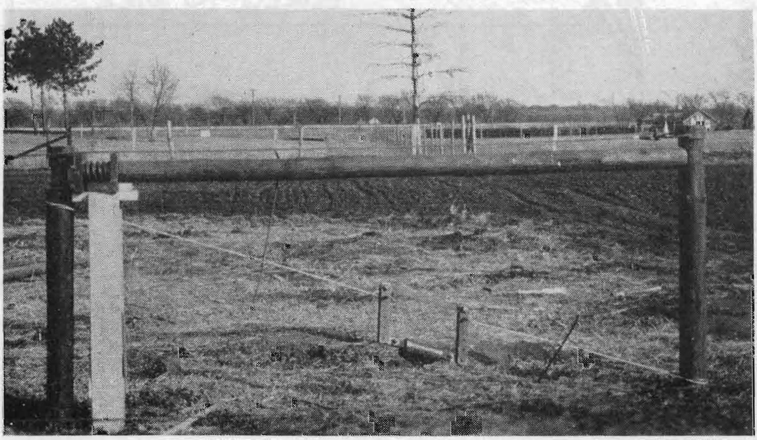


Fig. 37. Fence end ready for testing with apparatus for measuring brace loads in place.

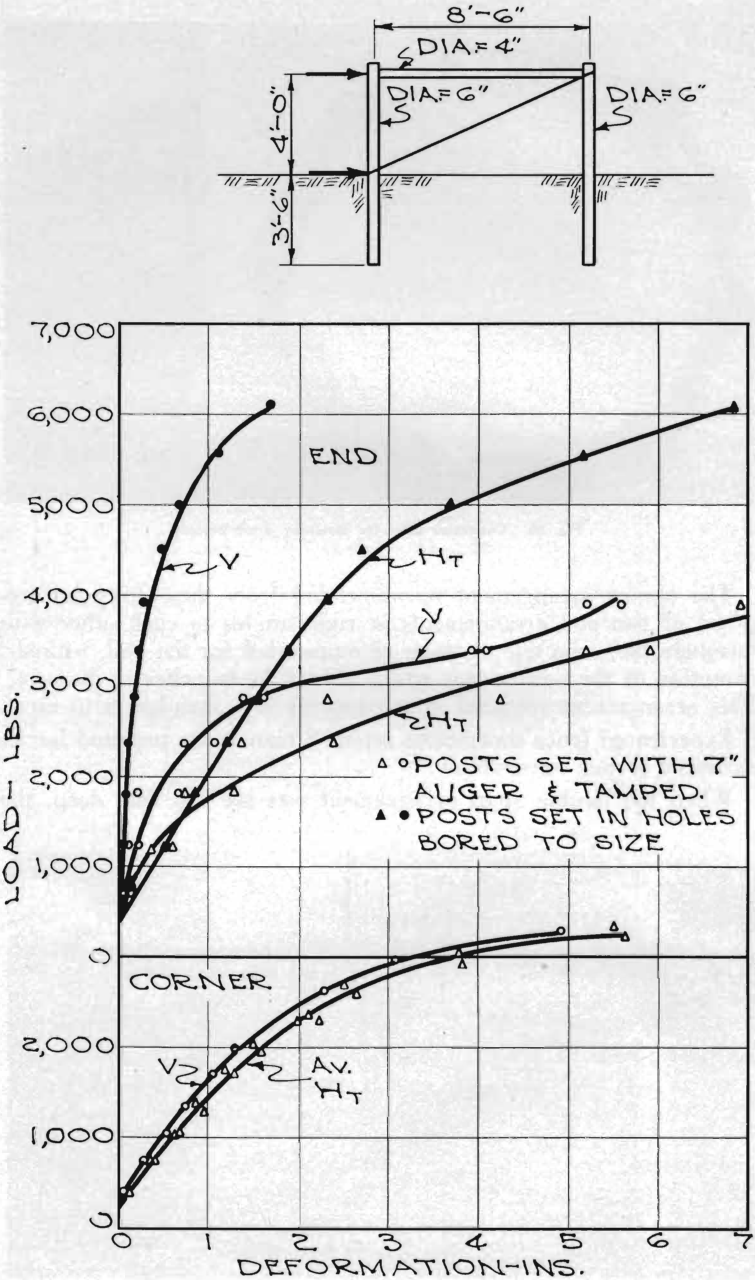


Fig. 38. Performance of single ends and corners.

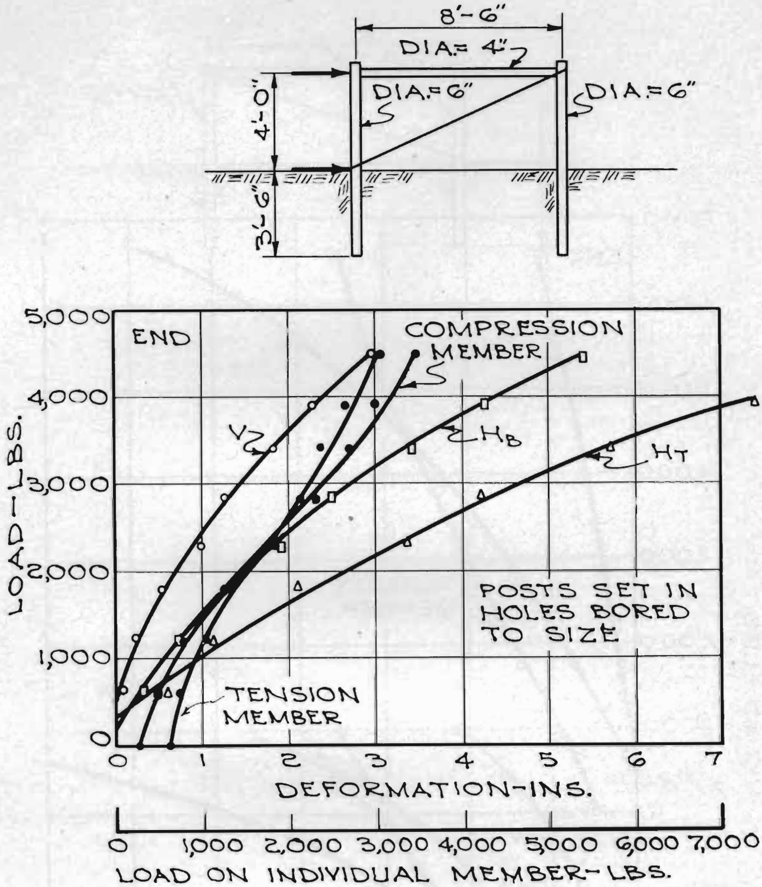


Fig. 39. Performance of single ends and corners.

structure folded up and twisted out of line at a very small load when compared with the constructions set 3½ feet deep.

The previously established loading of 3,000 pounds was used in calculating the end construction member sizes. The exact earth pressure on the portion of the post below the ground line could not be determined, but it was known from the structural analysis that the pressure could be resolved into a resultant at some point below the ground. To determine the resultant and its line of action, free-body diagrams of the end posts were drawn, as shown in figs. 53 and 54. The load was applied uniformly and the brace loads determined from the brace load formulas given in fig. 54, which were taken from pressure data as plotted in the figures as indicated. Only the horizontal forces were considered, as the soil friction around the

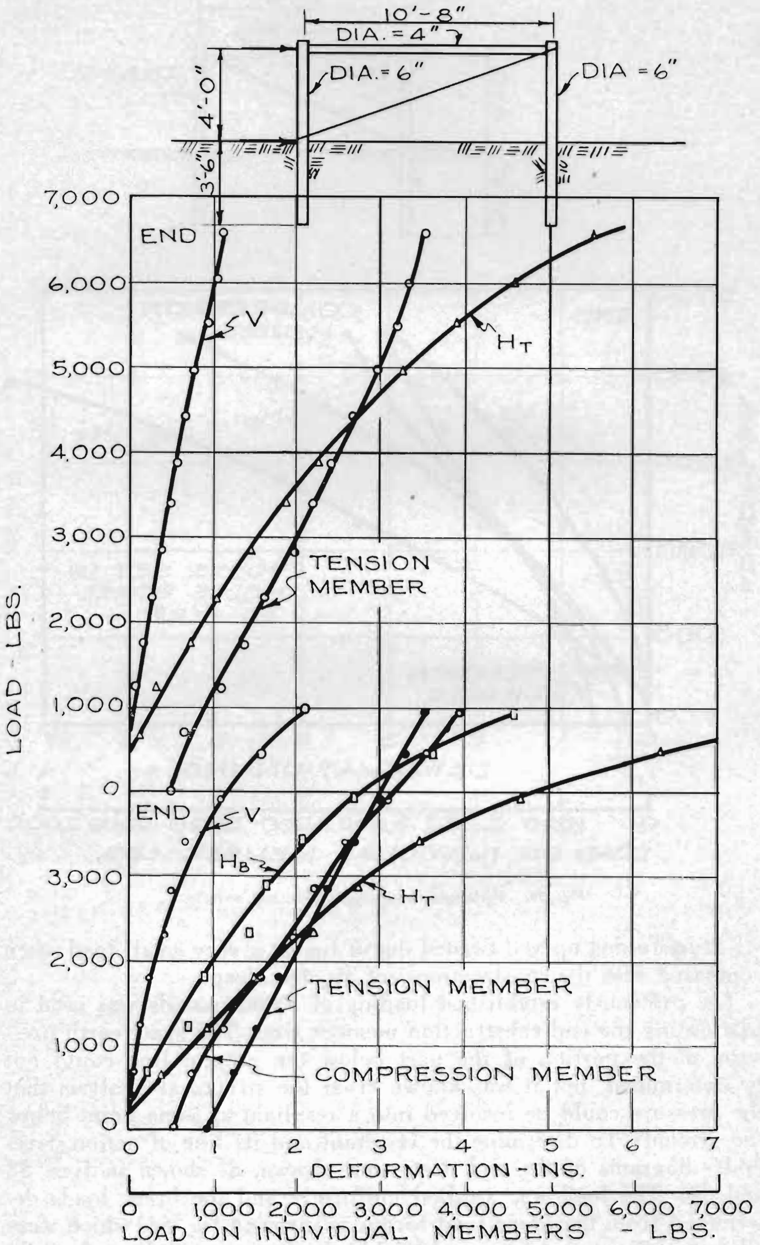


Fig. 40. Performance of single end with member loads indicated.

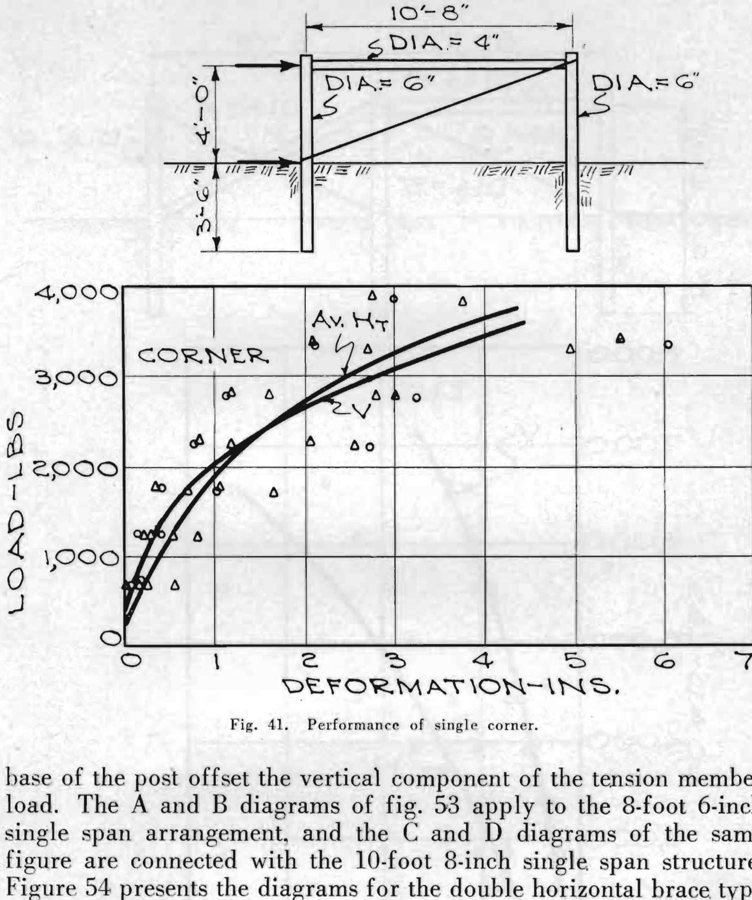


Fig. 41. Performance of single corner.

base of the post offset the vertical component of the tension member load. The A and B diagrams of fig. 53 apply to the 8-foot 6-inch single span arrangement, and the C and D diagrams of the same figure are connected with the 10-foot 8-inch single span structure. Figure 54 presents the diagrams for the double horizontal brace type of arrangement. The magnitude of P′ was determined by the summation of horizontal forces, and its line of action was obtained by taking moments about R_B.

The force P″ for the middle post in the double span was obtained in much the same manner as was P′. The diagrams for this post are given in fig. 54. In making computations on the end brace posts of all the arrangements, the line of action of the two resultant forces, P‴ and R, acting beneath the ground line, were obtained from the material presented by Seiler (10) and shown in fig. 15. The magnitudes of these same forces were obtained by taking moments about one and solving for the other.

The shear and moment diagrams, shown in figs. 53 and 54, were drawn after the forces which acted on the various posts were determined. The maximum moment was used to determine the post

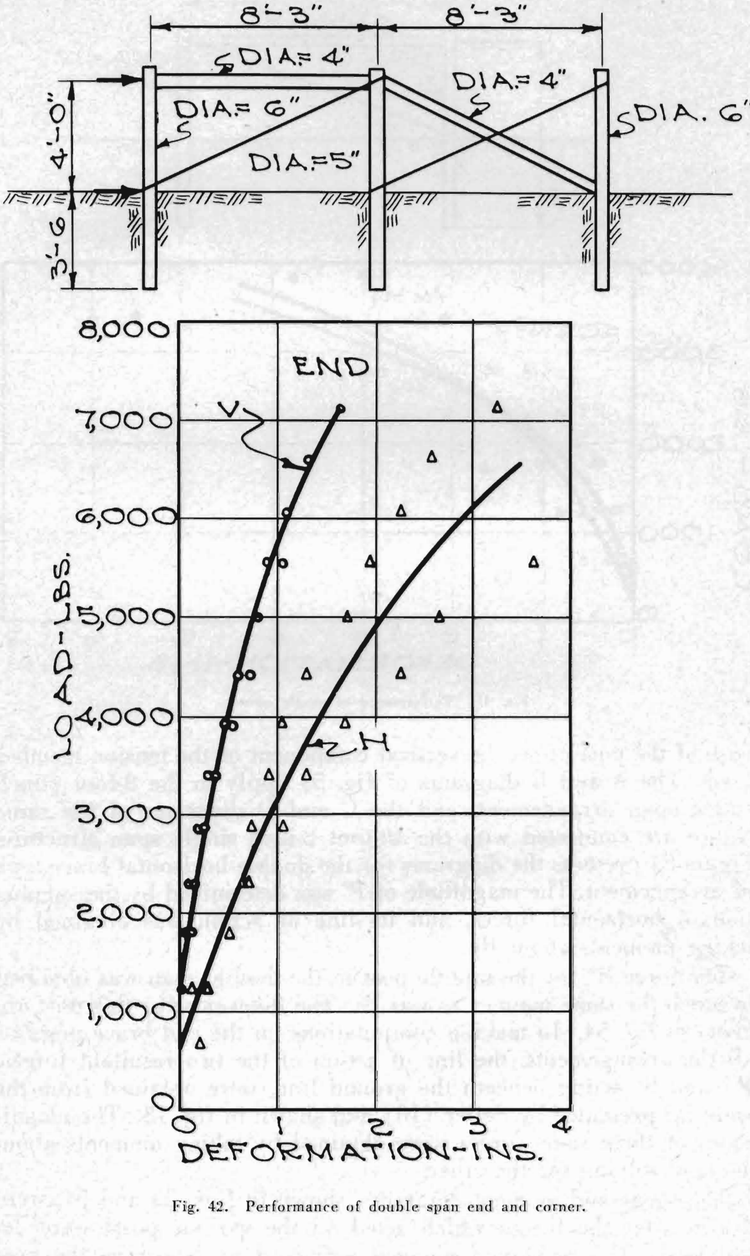


Fig. 42. Performance of double span end and corner.

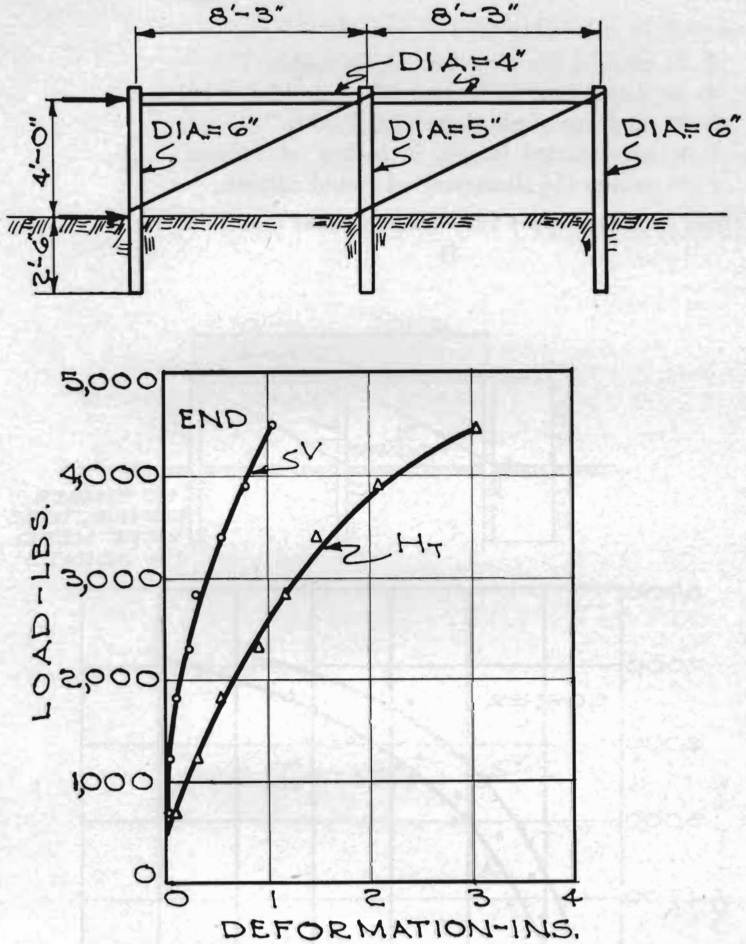


Fig. 43. Performance of double span end and corner.

diameters of the three types of arrangement. The formula used in these calculations was $S = Mc/I$, where S = allowable stress in pounds/inch², M = maximum moment, and I/c = section modulus of the post. The size of the compression braces was determined from the formulas (8):

$$P = \frac{0.274Ad^2E^2}{l^2} \text{ for rectangular members}$$

and

$$P = \frac{0.274E\pi^2r^4}{l^2} \text{ for round members}$$

when P = allowable load in pounds

A = area of the cross section in inches

d = dimension, in inches, of least side of column

E = modulus of elasticity (1,600,000)

l = unsupported length, in inches, of column

r = radius ($\frac{1}{2}$ diameter) of round column.

These formulas apply for $\frac{l}{D}$ ratios greater than K where

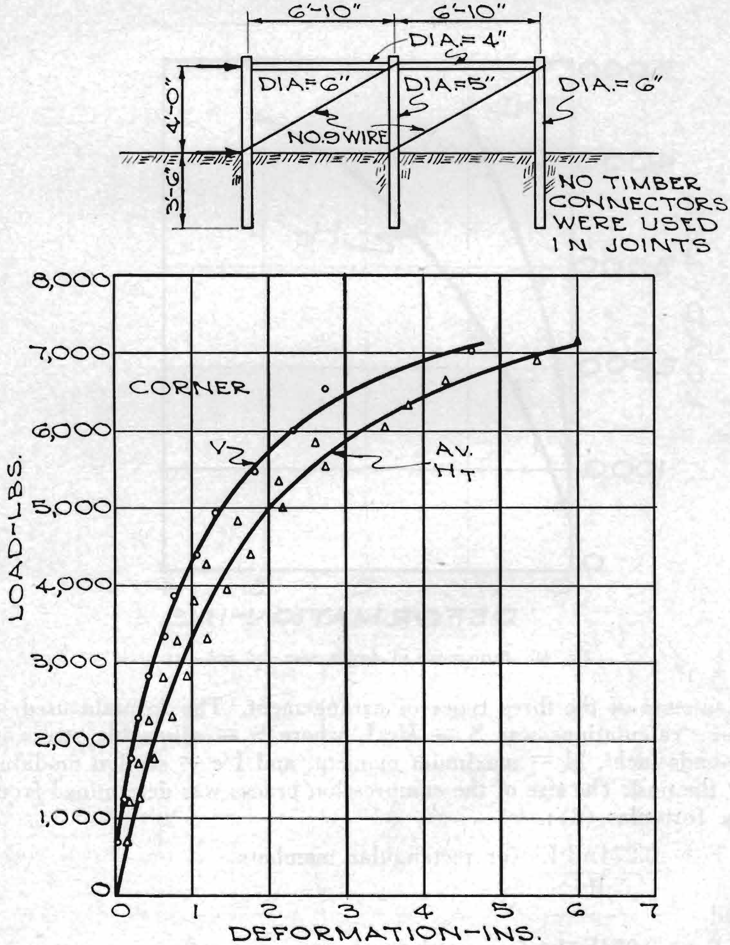


Fig. 44. Performance of double span end and corner.

$$K = 0.64\sqrt{\frac{E}{S}}$$

For steel compression members, the formula

$$S = \frac{18{,}000}{l} + \frac{l^2}{18{,}000r^2} \quad \text{was used.}$$

l = length of column in inches
r = radius of gyration in inches
S = allowable unit stress

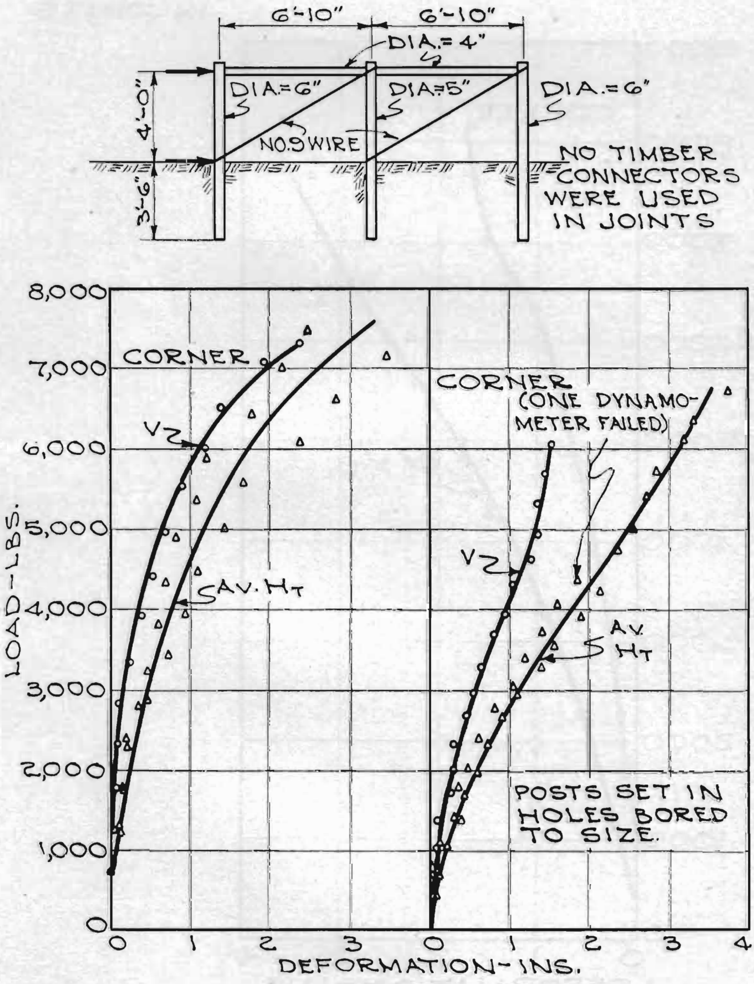


Fig. 45. Performance of double span end and corner.

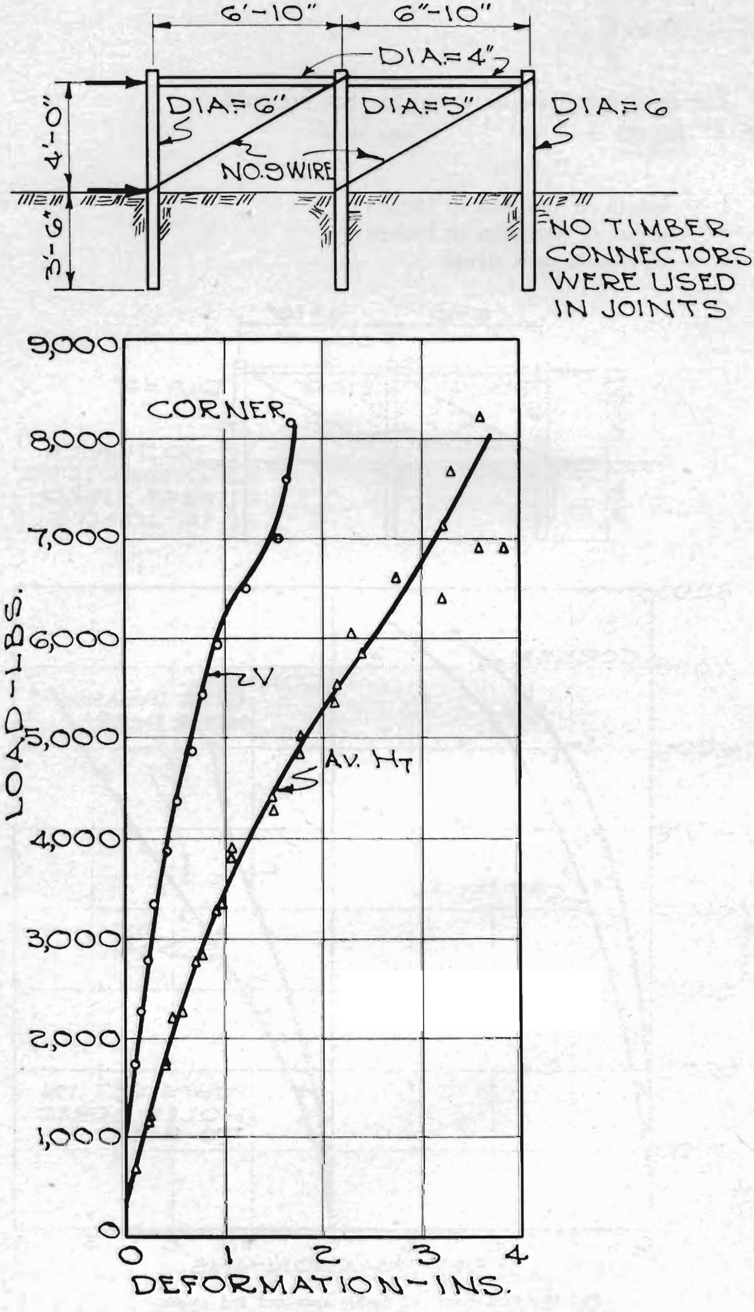


Fig. 40. Performance of double span end and corner.

(applicable when $\frac{l}{r}$ ratio falls between 100 and 200)

The following is a result of the calculations for compression braces:

Type of Brace	Calculated Allowable Load
(1) 2" steel pipe 11' in length	7,600 lbs.
(2) 1½" steel pipe 9' in length	5,300 lbs.
(3) 4" x 4" (full size) x 11' wood member	6,400 lbs.
(4) 4" x 4" x 11'-0 (actual 3⅝ x 3⅝)	4,350 lbs.
(5) 4" round wood member 11' in length	5,000 lbs.
(6) 3" round wood member 11' in length	1,600 lbs.

The breaking load for a single strand of No. 9 gauge standard smooth galvanized wire is approximately 1,400 pounds. The allowable stress on wire is usually taken from 1/3 to 1/5 of the breaking strength so the allowable load on a double strand of No. 9 wire would be approximately 900 pounds. For a double strand of No. 12½ gauge barbed wire the allowable load would be 850 pounds.

The following is a result of the calculations on the end member sizes:

Type of Member	Minimum Size
8' - 6" Single Span	
End post (8' - 0")	6" post
Brace post (8' - 0")	4½" post
Compression member (8' - 0")	4" post
Tension member	2 double strands of No. 9 wire
10' - 8" Single Span	
End post (8' - 0")	6" post
Brace post (8' - 0")	5" post
Compression member (10' - 2")	5" post
Tension member	2 double strands of No. 9 wire
16' - 6" Double Span	
End post (8' - 0")	5" post
First brace post (8' - 0")	4" post
End brace post (8' - 0")	3½" post
First compression member (8' - 0")	4" post
Second compression member (8' - 0")	3½" post
Tension members	2 double strands of No. 9 wire

The brace load constants will vary with the conditions of the set and the soil type. In the calculations on the member sizes, ample factors of safety were chosen to provide for any discrepancies in the brace loads resulting from changed conditions.

The double span arrangement required about 2½ man-hours to dig the holes and set the structure.

The superiority of the double span over the single span has been shown. Experience in connection with the tests suggested further possible improvements which have not been explored. Possible improvements are:

1. The double span end fails by buckling (fig. 52) rather than by movement out of the ground. A continuous compression member ex-

tending over both spans and capable of carrying considerable bending moment might materially improve its load-carrying capacity.

2. Preliminary tests on small-scale models showed a double span with cross braces as shown in fig. 9 was definitely superior to the horizontal brace (figs. 43, 49, 50, 51) if the load were applied to the middle post of the assembly. With this construction, any tendency of the middle post to lean in the direction of the applied force is accompanied by a tendency for the other two to lean backward thus offering still greater resistance toward movement out of the soil.

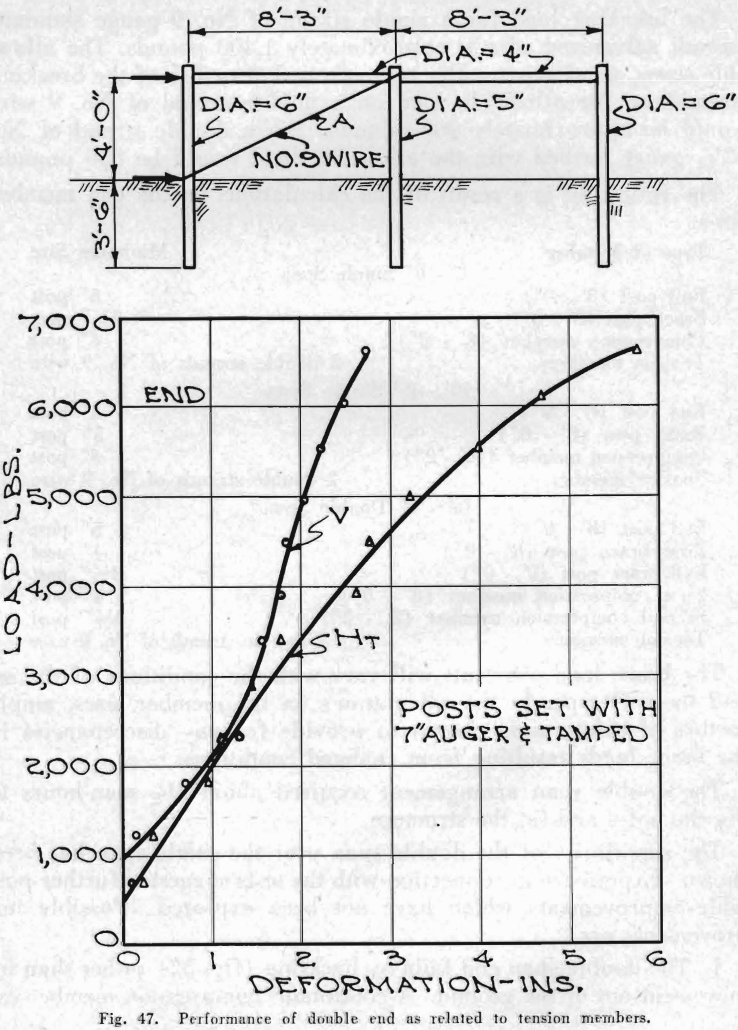
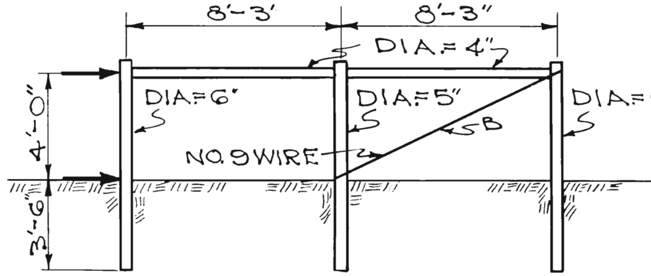


Fig. 47. Performance of double end as related to tension members.



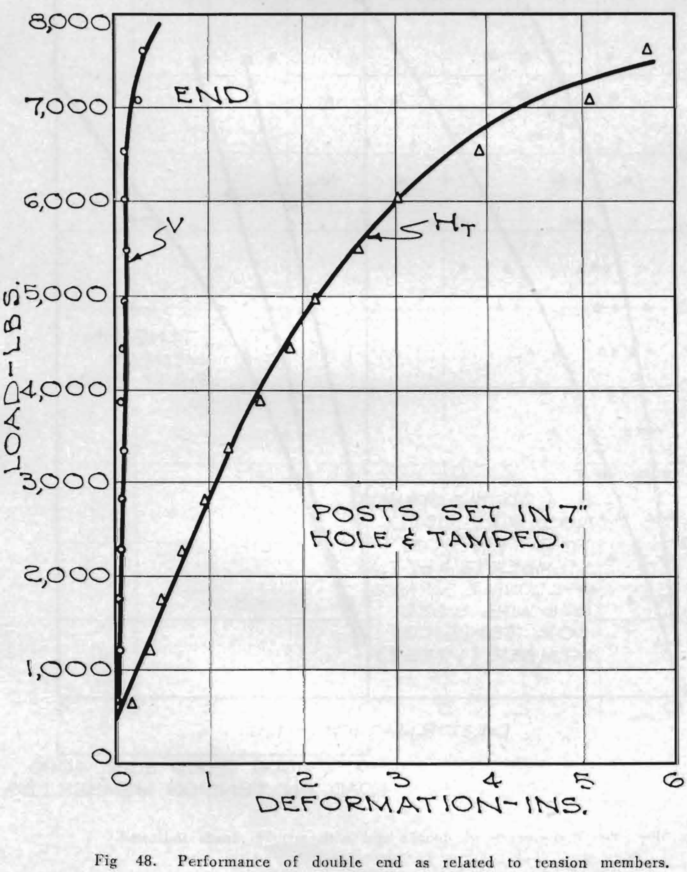


Fig 48. Performance of double end as related to tension members.

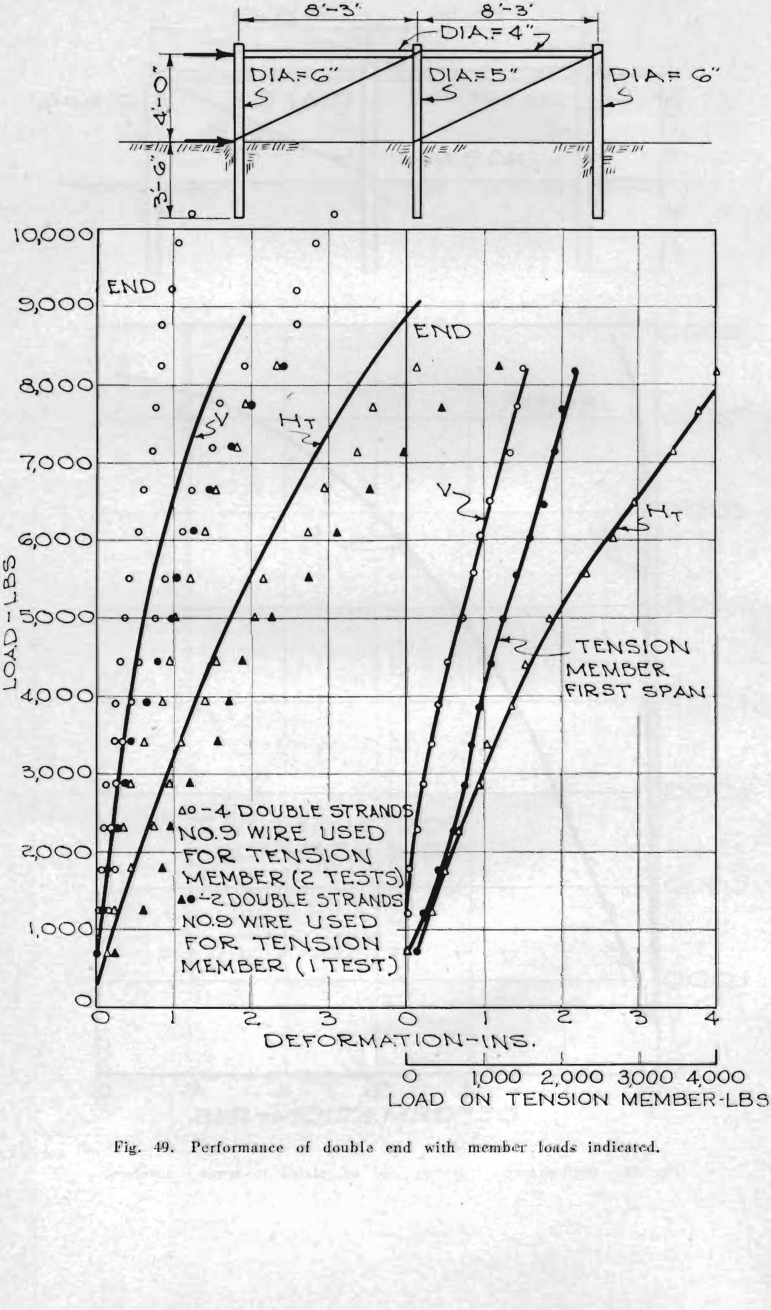


Fig. 49. Performance of double end with member loads indicated.

Models were made from steel rod to the scale of $1\frac{1}{2}'' = 1' \cdot 0''$. Vertical posts were $\frac{7}{16}$ of an inch in diameter and the braces $\frac{1}{4}$ of an inch in diameter. Loads were applied similar to those in the field tests. The attempt made first was to determine whether pulling from the middle post or second brace post would improve the performance of the double span. It seemed reasonable that the buckling would be reduced or eliminated by that means. Tests were made in a laboratory box, the posts set to the scale equivalent to 3 feet 6 inches and the soil tamped thoroughly. When the load was applied to the end post, failure occurred by the customary buckling experienced in the

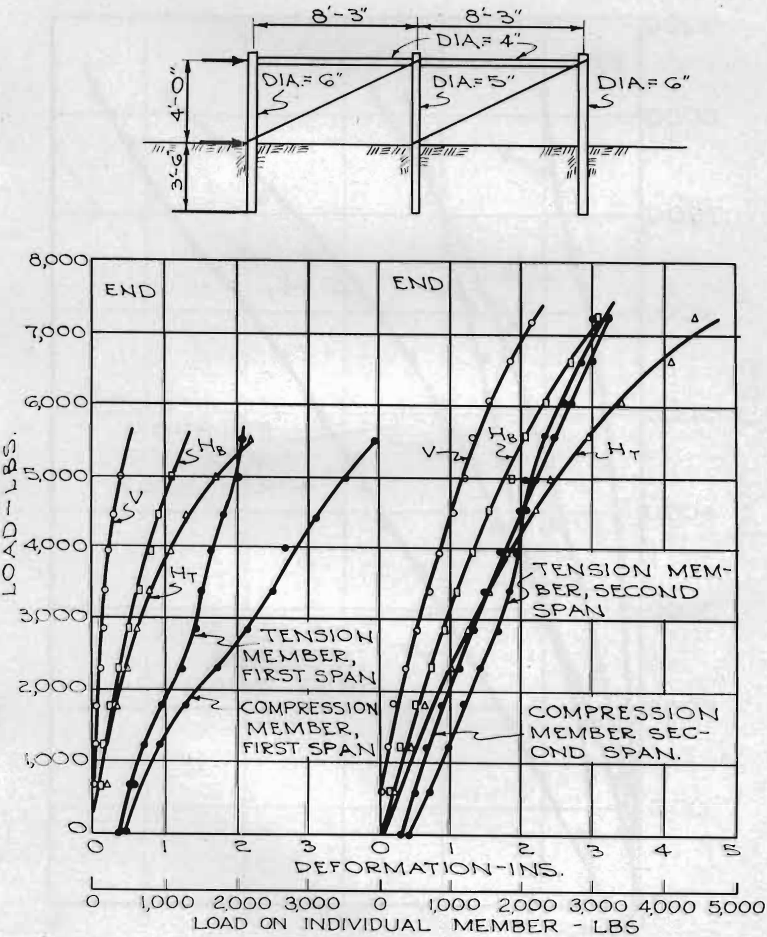


Fig. 50. Performance of double end with member loads indicated.

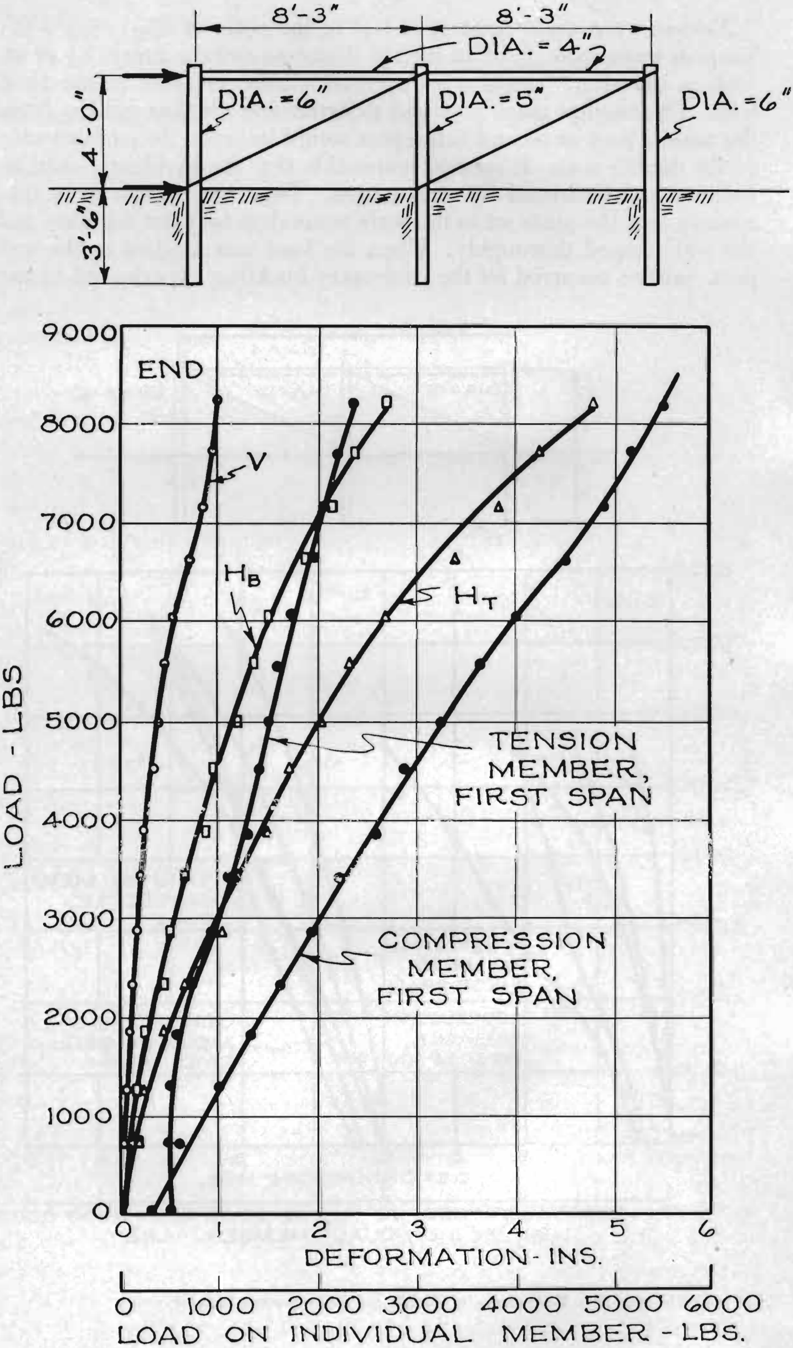


Fig. 51. Performance of double end with member loads indicated.

field tests. Loading the middle post or the second brace post (front post with reference to the pulling mechanism) resulted in a different type of failure but no significant improvement in performance. The entire model moved from the soil as a unit, much like the behavior of the single span end.

Another double span model was constructed with diagonal braces. When the load was applied to the middle post of this assembly the performance was definitely improved. The laboratory tests made could not be taken as valid proof of the approximate superiority, and there has been no opportunity for making field tests. It would appear however that the advantage might be as great as 60 percent. In practice there would probably be some objection to stretching the woven wire to the middle post and later fastening a short length from this to the end post. This difficulty would not present itself with the barbwire. Perhaps the practical solution would be to stretch the woven wire to the end post as usual and to stretch the barbwire to the middle post. Since the barbwire causes the greatest increase in load due to temperature changes, the advantages would still be retained. There is a possible additional advantage due to the fact that the forces caused by the barb and woven wire would tend to oppose each other with reference to the direction of post rotation.

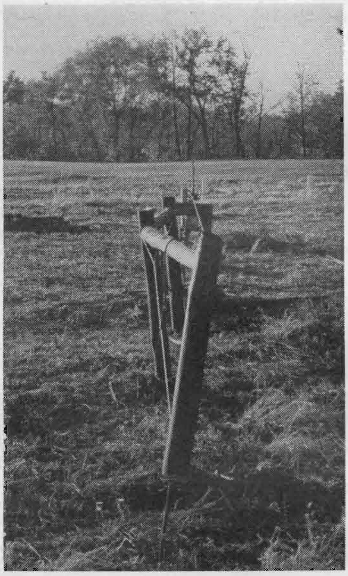


Fig. 52. Characteristic failure of double span assembly.

TIME TEST

The objects of the time test were to compare the structural aspects of the single and double span under actual fence loads and to set up criteria by which the action of other end structures might be predicted. The assemblies as detailed in figs. 38 and 42 were chosen because the single span arrangement was a common type observed in the field while the double span assembly had given the most satisfactory results in the tests.

The end post of the single span was 6 inches in diameter and the brace post 5 inches. The end post of the double span was 4 inches in diameter and the other two posts only 3 inches.

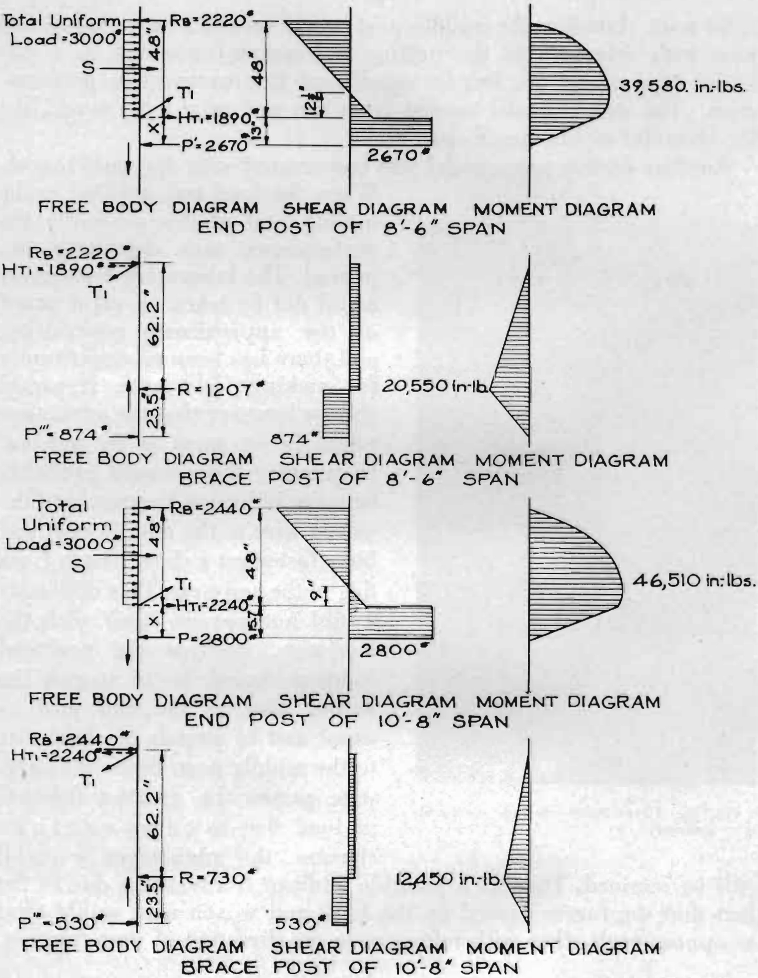


Fig. 53. Load, shear and moment diagrams for posts for single span ends.

The fence comprised two 15-rod sections of 832-6-11 woven wire with four strands of barbwire above. The barbwire consisted of two strands of No. 12½ gauge wire and was spaced at 3, 4, 5 and 7-inch intervals. Line posts consisted of sawed halves made from round posts 4½ to 5½ inches in diameter and 7 feet in length.

An anchor post was set halfway between the two ends to furnish a place to insert the dynamometer for reading the loads in the fence and to serve as a fixed end so the individual characteristics of the assemblies could be studied.

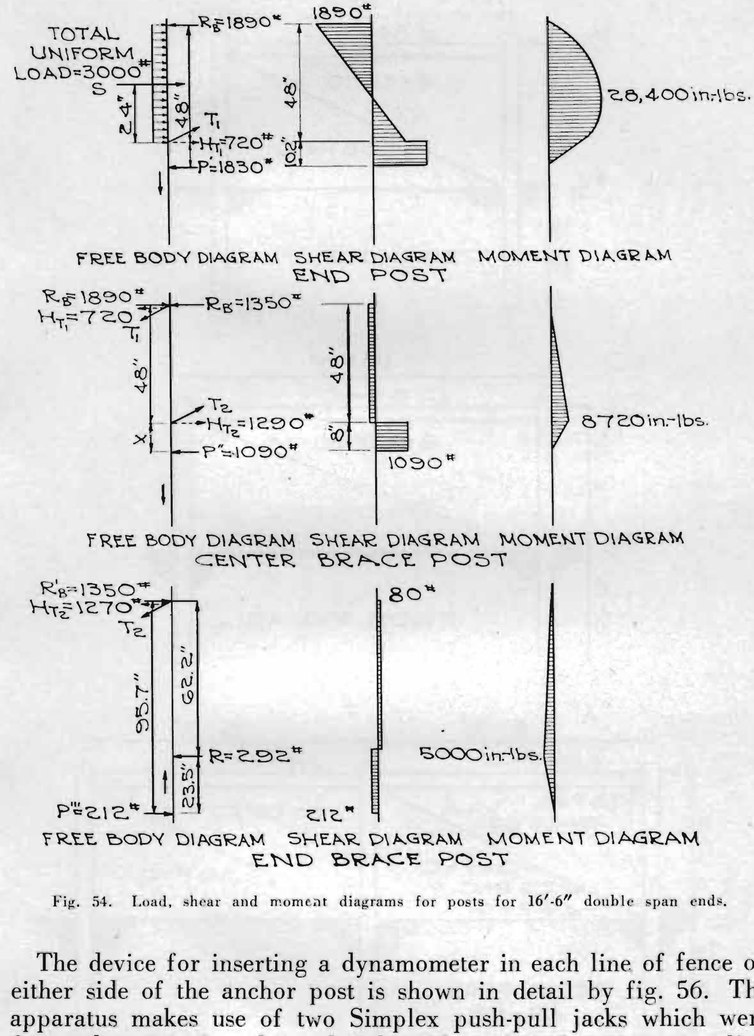


Fig. 54. Load, shear and moment diagrams for posts for 16′-6″ double span ends.

The device for inserting a dynamometer in each line of fence on either side of the anchor post is shown in detail by fig. 56. The apparatus makes use of two Simplex push-pull jacks which were fastened to 1-inch rods, and tightened so that the connecting link could be removed. The dynamometer was bolted in place and the jacks released, placing the load on the dynamometer. The bolt near the anchor post was used to draw the fence to the proper tension on the initial stretch.

The single span end was set on the north side of the plot near a grove of trees in Webster clay loam soil. The surface soil to a depth of 10 to 12 inches consisted of a black, silty clay loam grading into black, rather compact, fine-grained plastic clay which at a depth of

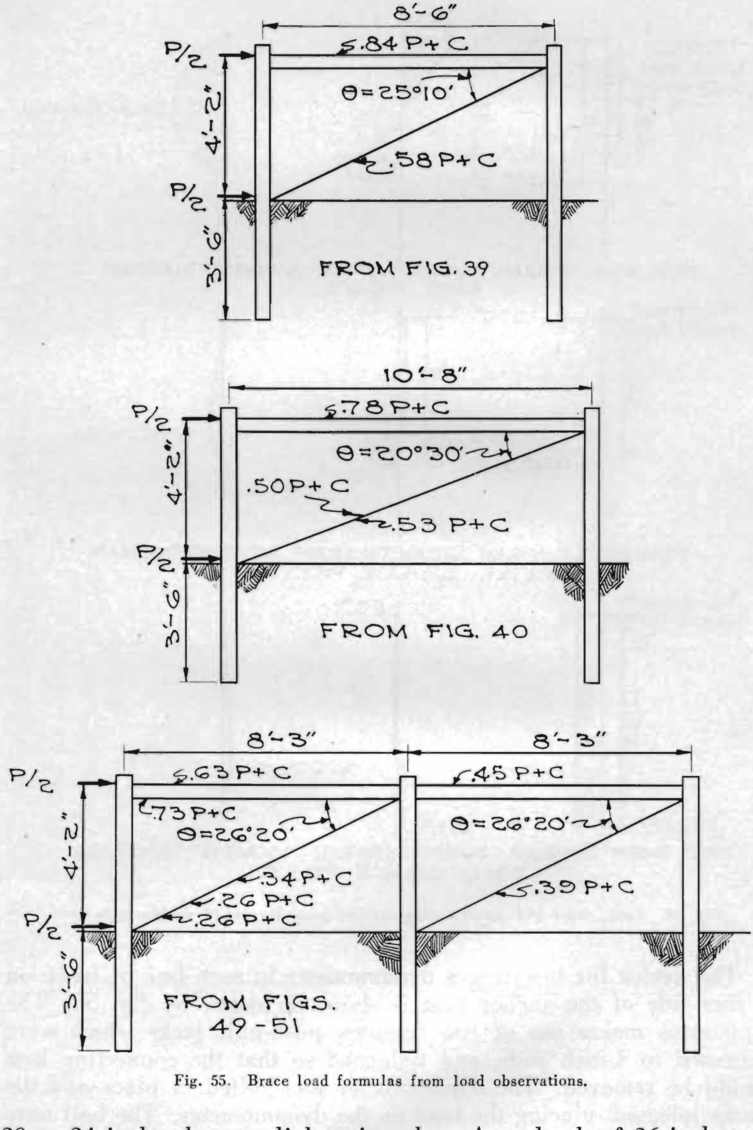


Fig. 55. Brace load formulas from load observations.

20 to 24 inches became lighter in color. At a depth of 26 inches a layer of fine gravel was encountered.

The double span was set on the higher ground. The soil type at this end was Clarion loam, with the surface soil being dark grayish-brown friable loam, extending to a depth of approximately 12 inches. The subsurface soil, to a depth of 24 inches, was a medium

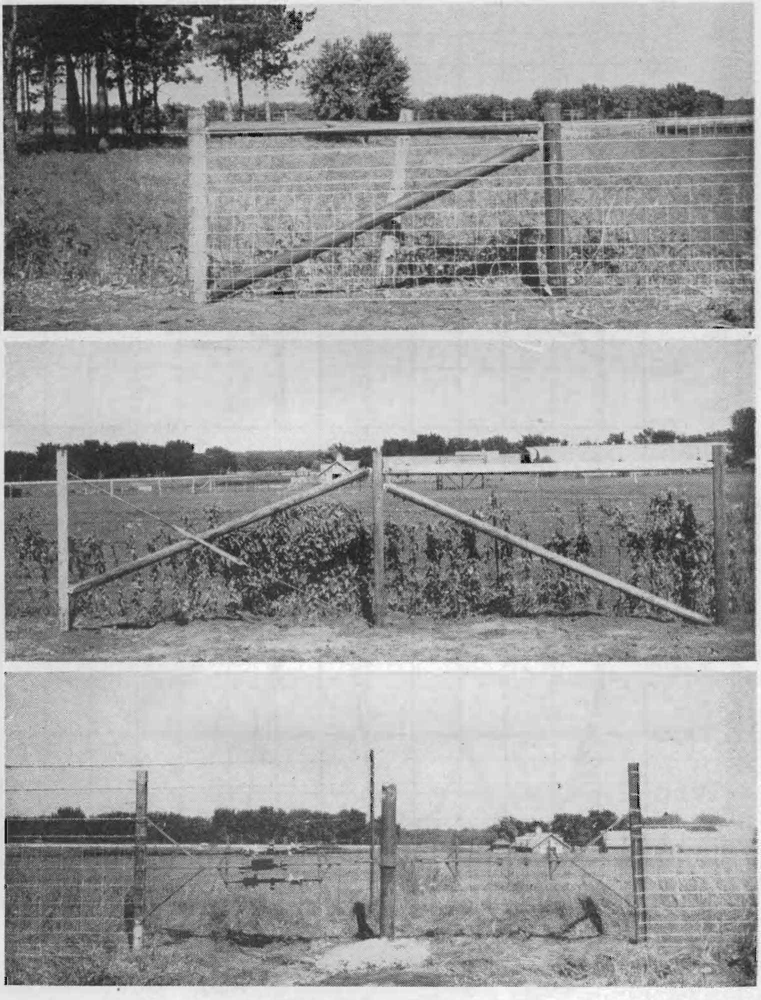


Fig. 56. Single span, double span and anchor used in the time tests.

brown loam, changing to a yellow silty clay loam and at 42 inches contained quite a bit of gravel.

The ends were allowed to settle for a few days before the wire was stretched. Care was taken to insure a straight fence. Line posts were set 2½ feet deep. Concrete bench marks were set just back of the posts, deep enough to insure against any possible upheaval from frost action. A double jack stretcher was used on the woven wire and a block and tackle on the barbwire. Two rolls of woven

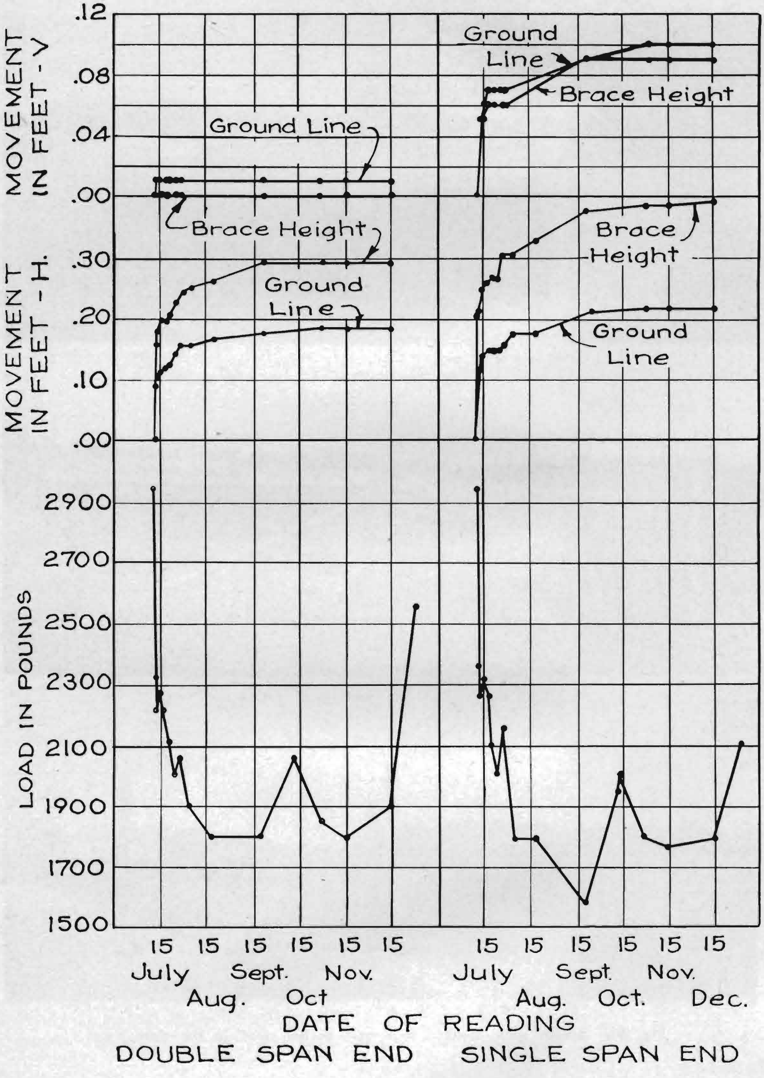


Fig. 57. Comparison of load and movement of the time test ends.

wire were used, one being fastened to the end construction and the other to the I-beam at the anchor post. The double jack stretcher was fastened in the middle and the wire pulled taut. A center splice was made, and before the jacks were released, a hand tool was used to crimp the wire between the clamps of the stretcher to remove any slack.

In stretching the wire an effort was made to follow Reynolds' (9) suggestion of removing one-half the tension curve. This was not followed through, however, as the load became so much larger than the 1,600 pounds which had been recommended. The barbwire was stretched with an initial tension of 250 pounds per strand. When the wire was fastened in place, the bolt at the anchor post was tightened until the load was 2,942 pounds. The staples were left partially driven so the wire would have room to slide back and forth.

The two end structures after the test had been set up are shown in fig. 55.

Load observations were made at the time movement readings were taken and during part of the winter when only temperature data were taken.

During the test, observations of load, movement of end post, elongation of tension curves and air temperature were noted.

Most of the observed change in load and end movement (fig. 57) took place immediately following the loading operation. At the end of this period both ends had twisted slightly out of line and the members of the double span were showing signs of overstress. Members of the single span had not shown signs of overstress due to their larger size.

A number of factors affected the load readings, such as movement of the ends, temperature, wind and sunlight.

The vertical movement indicates that the double span is superior to the single span. The double span moved slightly in a vertical direction during the stretching operation, but since that time has remained level. The single span end has displayed quite different characteristics in this mode of failure. During the first two months most of the movement took place. The lesser vertical movement in the double span arrangement is due to the advantageous structural features displayed by this construction. The second span relieves part of the load carried by the tension member, and only through this member can vertical uplift be produced on the end post. Therefore a decrease in the tension load naturally decreases the vertical movement.

The load on both fences dropped approximately 20 percent during the first 24 hours and almost 40 percent in the first month. In spite of the fact that the single span end moved the greater distance of the two end constructions, the load remained slightly higher during the first month. This condition can be explained by pointing out that the single span end moved farther during the loading operation. If the differences in movement at the ground line taken between July 13 and Aug. 19 are considered, the double span moved farther. After Aug. 19 the load reading on the double span remained higher than that of the single span. The load reading is dedependent not only upon the movement but upon changes in temperature. Peaks occurring in the load curve can be accounted for by a drop in temperature.

The greatest factor contributing to permanent drop in load prior to complete failure is horizontal movement of the end post.

During December, January and February a dynamometer was left in one or both fences at all times, and readings were taken at various periods throughout the day. Temperature and extensometer readings were usually taken simultaneously with the load readings. The extensometer readings were discontinued during the latter part of January and February. These readings indicated the elongation of a wire tension curve chosen at random in the fence. From Dec. 17 to Dec. 27 the extensometer was placed on a tension curve of the top No. 9 gauge wire in the double span end fence, from Dec. 28 to Jan. 1 the instrument was placed on one of the No. 11 gauge intermediate wires of the same fence, and during the time between Jan. 1 and Jan. 12 the extensometer was placed on the top No. 9 gauge wire of the single span end fence.

Figure 58 presents the elongation of the wire tension curves in the fences. The dotted line represents the theoretical elongation of a straight piece of wire for the given changes in temperature. In plotting the elongation of the various wires, the difference in extensometer readings rather than the actual readings was plotted. The lower graph presents the change in load with the change in temperature.

In studying the action of the tension curves, the two graphs were considered together to obtain a comprehensive picture of the importance of the curves. First of all, one must consider that a larger part of the fence consisted of straight wire than was contained in the curves, and a greater percentage of the wire clamped in the extensometer was included in the tension curve than when the total length of wire between curves is considered. With these thoughts in mind an analysis was made. At the higher temperatures, the wire in the specimen elongates more for a given change in temperature than would a straight unloaded wire for the same change in temperature, because the wire in the fence is more or less fixed and a change in temperature increases the load, thus producing a tendency for the wire to elongate. The tension curve elongates more easily than does the straight wire. Therefore, the part of the wire contained within the instrument not only elongates for that wire within the extensometer, but for the straight part outside. Most of the increase in fence tension due to temperature was no doubt due to the four barbwires. Since they contained no tension curve there was no way to dissipate the shrinkage due to temperature. If the temperature drops from 70° to 20°F. the wire decreases 0.0585 percent

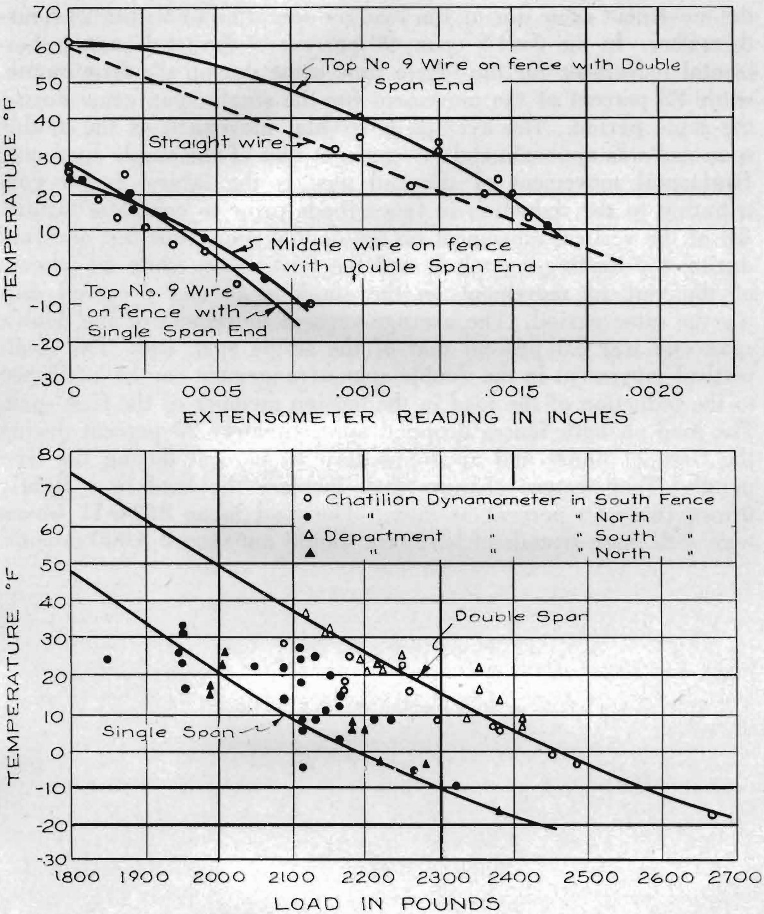


Fig. 58. Load and deformation in tension curve as related to temperature.

of its length. But since it is fixed at both ends the shrinking tendency would cause an increase in tension instead, which, for 8 - $12\frac{1}{2}$ gauge wires, would be 970 pounds. If the temperature drop would manifest itself in fence shrinkage (barbwires), a quarter mile fence would decrease in length 0.77 feet. Apparently temperature is one of the agents which contribute to end failure.

A drop in temperature from 70° to 20° F. gave an increase for the entire fence under test of approximately 900 pounds, or 50 percent in the load.

From these tests it appears in five months of observation on horizontal movement of both ends, approximately 50 percent in the movement came during the loading operation or within 24 hours thereafter. In the double span, 90 percent of the total average horizontal movement for the whole time came during the first month, while 83 percent of the movement for the single span came during the same period. The average horizontal movement of the double span end was approximately 80 percent that of the single span end. Horizontal movement of the end post is the largest factor contributing to the reduction in fence loads prior to complete failure. All of the vertical movement on the double span, thus far, occurred during the loading operation and the first night, while 50 percent of the vertical movement on the single span end occurred during the same period. The average vertical movement of the double span end was 5.3 percent that of the single span end. The small vertical movement in the double span arrangement can be attributed to the reduction of the load in the tension member of the first span. The load on both fences dropped approximately 20 percent during the first 24 hours and approximately 40 percent during the first month. Temperature changes may increase the load in a tightly drawn fence 50 percent or more. The load in an 832-6-11 woven wire with three strands of barbwire should not exceed 3,000 pounds.

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